ASSESSMENT OF ENERGY PERFORMANCE OF GREEN ROOF EFFECTS FOR A RESIDENTIAL BUILDING IN HOT HUMID CLIMATE

BY

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Dedicated to My Parents, Wife and Family

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LIST OF ABBREVIATIONS

ASHRAE :	American Society of Heating, Refrigerating and Air
ACH:	Air Changes per Hour
BPS:	Building Performance Simulation
CBA:	Cost benefit Analysis
CFL:	Compact Fluorescent Lamp
DOE:	Department of Energy
DHW:	Domestic Hot Water
DXF:	Drawing Exchange Format
EPDT:	Ethylene Propylene Diene Terpolymer
GUI:	Graphical User Interface
HVAC:	Heating, Ventilation and Air Conditioning
IECC:	International Energy Conservation Code
IEQ:	Indoor Environmental Quality
IAQ:	Indoor Air Quality
IEO:	International Energy Outlook
IECC:	International Energy Conservation Code
KFUPM:	King Fahd University of Petroleum & Minerals
LEED:	Leadership in Energy and Environmental Design
LAI:	Leave Area Index
LCC:	Life Cycle Cost Analysis
NPV:	Net Present Value
MTOE:	Millions Tonnes of Oil Equivalents
SCDSI:	Saudi Central department of statistic and information
TWh:	Terra Watt Hour
SEC:	Saudi Electricity Company
SEEC:	Saudi Energy Efficient Center
WHC:	Water Holding Capacity
WES:	World Energy Statistic

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ABSTRACT

Saudi Arabia is facing a rapid growth in energy demand much of which comes from the building sector as it accounts for over 76% of the total national electricity consumption. The residential sector alone consumes around 51% of the total electricity. The heating, ventilation and air conditioning (HVAC) systems make for the most of the energy consumption in building. The rapid economic growth and the need for new residential building to meet the needs of growing population indicate a steep rise in energy demand in the near future. The situation requires a paradigm shift in the energy consumption trends in the building sector also advocating for radical energy efficiency measures. Green roof which has a wide range of sustainability and ecological benefits while often enhancing the aesthetic qualities and architectural creativity of building was considered in this respect. This study examines the application of green roof on a 4-bedroom house at King Fahd University of Petroleum & Minerals (KFUPM), Saudi Arabia. A base case simulation model of the house is developed using DesignBuilder software tool and real time energy consumption data is used to validate the model. Results shows that compendium options that were applied on the developed model reduce the annual energy consumption by up to 36%, thus, decreasing the annual energy index of the house from 169kWh/m^2 to 109kWh/ m^2. Moreover, results of a cost benefit analysis have also been provided with an economic scale of ≥ 1 (Justified) or < 1 (not justified) to determine its cost to benefit ratio for a period of 15 years.

ملخص الرسالة

تواجه المملكة العربية السعودية نموا سريعا في الطلب على الطاقة، والحصة الأكبر من هذا الطلب تأتي من قطاع البناء حيث تشكل أكثر من 76٪ من إجمالي استهلاك الكهرباء الوطني. ان القطاع السكني وحده يستهلك حوالي 51٪ من إجمالي الكهرباء في المملكة. وتعتبر أنظمة تدفئة وتكييف الهواء (HVAC) هي الانظمة الأكثر استهلاكا للطاقة في المباني. ان النمو الاقتصادي السريع والحاجة إلى المباني السكنية الجديدة لتلبية احتياجات الزيادة السكانية النامية تشير إلى حتمية وجود ارتفاع حاد في الطلب على الطاقة في المستقبل القريب. ويتطلب هذا الوضع البحث عن نقلة نوعية في اتجاهات استهلاك الطاقة في قطاع البناء، كما يتطلب ايضا الدعوة إلى اتخاذ تدابير جذرية لتحسين كفاءة استهلاك الطاقة. ومن هذا المنطلق، تعتبر تقنية الأسقف الخضراء والتي لديها مجالات واسعة من الفوائد البيئية وفي مفهوم الاستدامة، ففي الوقت نفسه فإنها تعزز في كثير من الأحيان الصفات الجمالية والإبداع المعماري في تصميم المباني في هذا الصدد. وتأتي هذه الدراسة الهادفة الى اختبار تطبيق تقنية الاسقف الخضراء على مبنى سكني مكون من اربعة غرف نوم في جامعة الملك فهد للبترول والمعادن (KFUPM)، في المملكة العربية السعودية. لقد تم تطوير نموذج محاكاة الحالة الأساسية من ذلك المبنى باستخدام برنامج الحاسوب DesignBuilder، كما تم استخدام بيانات حقيقية واقعية لاستهلاك الطاقة في المبنى للتحقق من صحة النموذج. وتشير النتائج إلى أن خلاصة الخيارات التي تم تطبيقها على النموذج المطور تقلل من الاستهلاك السنوي للطاقة بنسبة تصل إلى 36٪، وبالتالي، انخفاض مؤشر الطاقة السنوي للمبنى من 169 كيلو واط ساعة\ متر مربع إلى 109 كيلو واط ساعة\ متر مربع. وعلاوة على ذلك، فقد تم ارفاق نتائج تحليل التكاليف والفوائد مع مقياس اقتصادي يتألف من 1 (مبررا) أو≥ 1 (ليس مبررا) لتحديد نسبة الفوائد الى التكلفة ولمدة 15 عاما.

CHAPTER ONE

INTRODUCTION

1.0 World Energy Consumption Scenario

The building sector has a crucial relationship with the global energy and environmental scenarios as it accounts for almost one third of the global energy use and nearly 40% of the resources consumed [SBCI, U 2009]. The role of buildings in future is set become even more crucial as the building stock grows. The situation leads to serious environmental concerns, mainly in the form of global warming due to increased greenhouse gases emissions, which are largely attributed to the growing fossil fuel consumption. According to International Energy Agency (IEA), world`s total final energy consumption has increased from 4,674 to 8,918 Mtoe in 40 years with maximum consumption from fossil fuels like oil, coal, natural gas. Figure 1.1 shows the world total final energy consumption from different sources [WES, 2013]

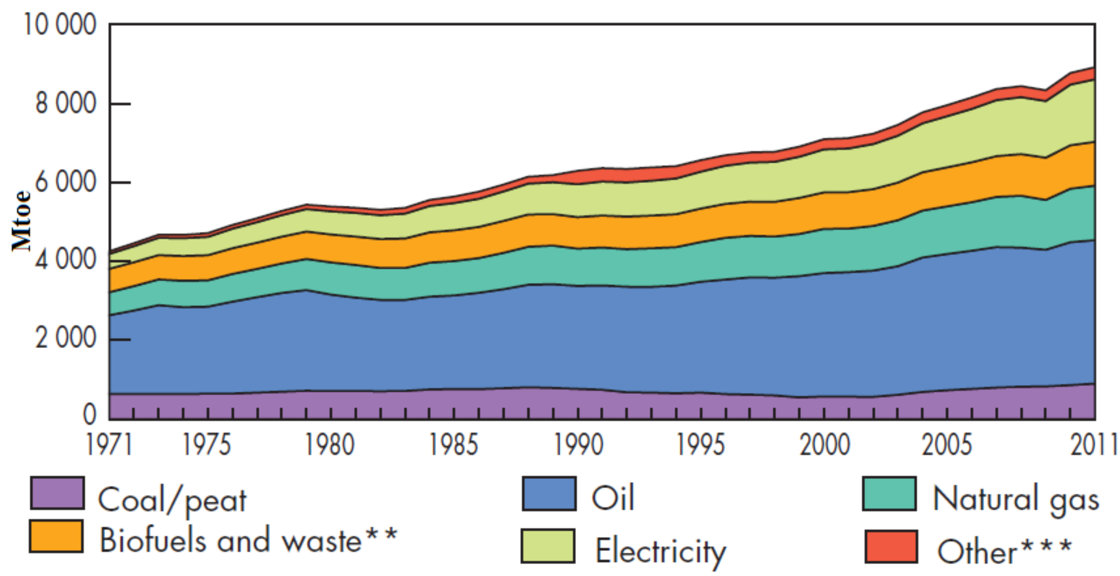

Figure 1.1: World total final energy consumption of different sources of energy from the year 1971 to 2011

If the focus is on type of energy, electrical energy by far has seen an increase of more than 90% from 1971 to 2011. In 1971, 9.4% (of 4,674 Mtoe) of the world total final energy consumption was electricity, which increased to 17.7% (of 8,918 Mtoe) by the end of 2011 as shown in Figure. 1.3. If electricity consumption by sector is assessed, the building sector has seen the maximum increase, from 44.1% (of 439 Mtoe) of the world total electrical energy consumption in 1971to 55.8% (of 1582 Mtoe) in 2011 as per IEA, Figure 1.2 In 2011, in terms of electricity generation by the type of fuel, 10.1% was from coal/peat, 15.5% from natural gas, 40.8% from oil and the rest from other renewable sources, 22,126 TWh of the total world electricity generation is from oil making fossil fuels the largest source for electricity generation [WES, 2013,].

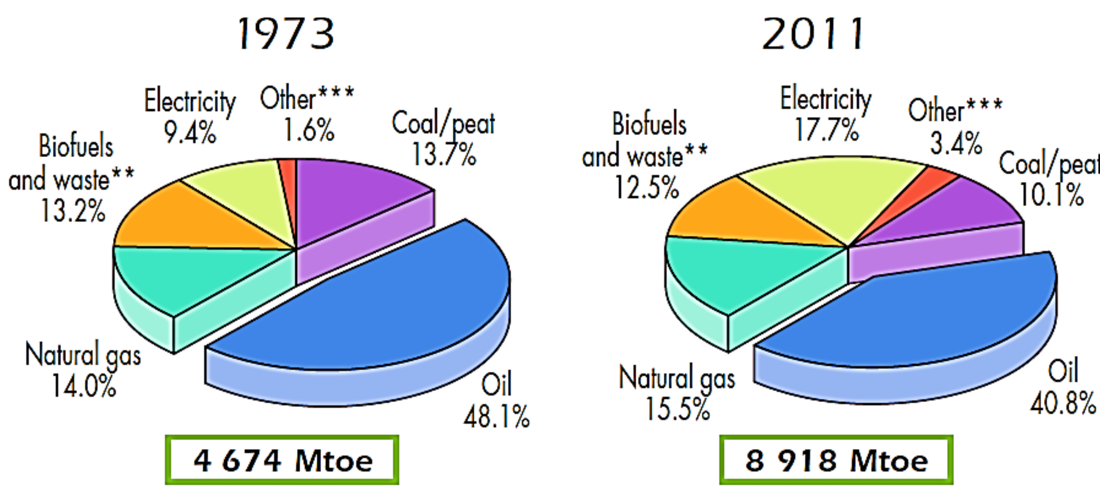

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Figure 1.2: world total final energy consumption of different sources of energy from the year 1971 to 2011 by %

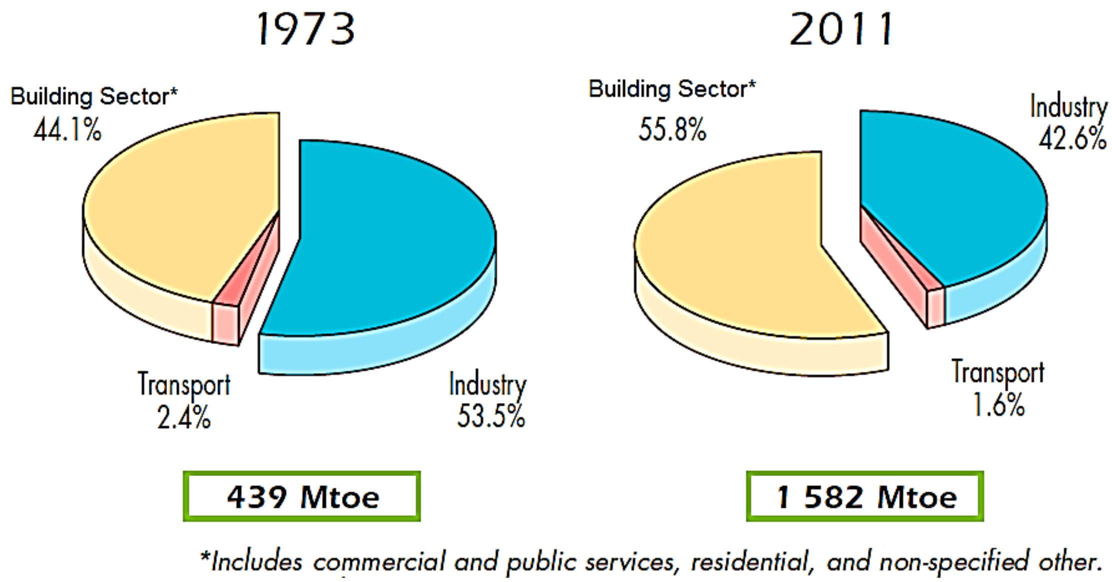


Figure 1.3: world total electrical energy consumption by sector in %

Middle East has also seen a significant increase in energy consumption from about 0.7% (of 4,674 Mtoe) of the world total energy consumption in 1971 to 4.8% (of 8,918 Mtoe) in the year 2011. Middle Eastern countries are primarily relying on fossil fuels in the form of oil and gas as their energy sources. Middle East is the largest oil producing region of the world accounting for 32.5% of the total production. KSA alone produces 13.1% of the world crude oil production, making it the largest producing country. Middle East is also the third largest producer of natural gas in the world with 15.8% in 2012 [WES, 2013,]. In term of electricity generation, 3.8% (of 22,126 TWh) of the total world electricity generation was in the Middle East in 2011, almost all of it coming from fossil fuels. U.S. Energy Information Administration’s International Energy Outlook 2013 projection to 2040 has reported that between 2010 and 2040 the world electrical generations will double reaching to around 40,000 TWh Figure 1.4 with similar fuel consumption trends projected for Middle East Figure 1.5. Electricity generation in the Middle East grows by 2.1 percent per year on average in the Reference case, from 758

TWh in 2010 to 1,405 TWh in 2040, reflecting the region's rapid growth in population, economic activity, and income. Over the projection period, natural gas-fired generation rises at a 2.5% average annual rate and slowly displaces oil-fired generation, which declines slightly, while its share of the region's power generation market falls from 34 percent in 2010 to 14 percent in 2040 (Figure 1.4) [IEO, 2013].

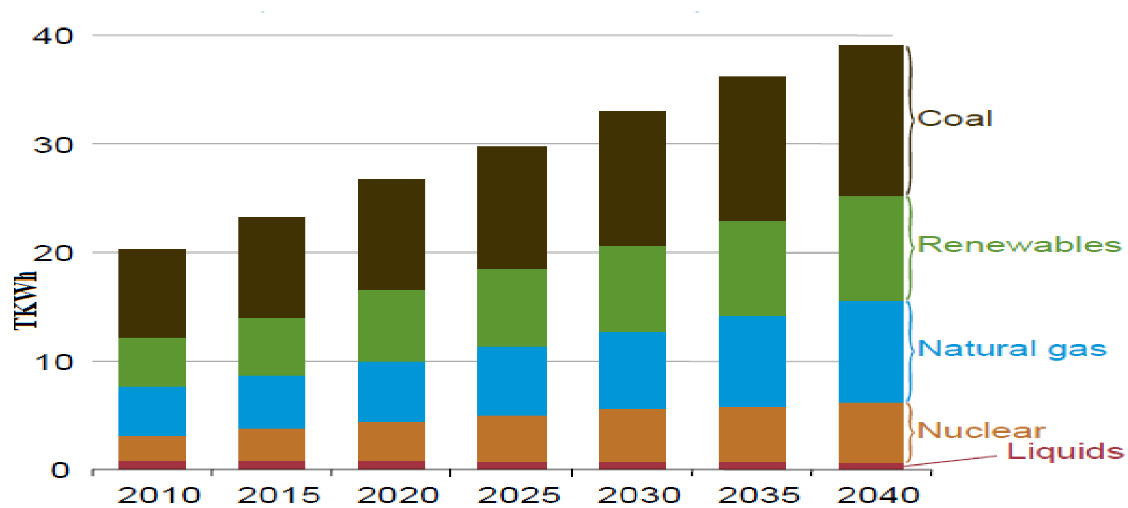


Figure 1.4: World net electricity generation by fuel, 2010-2040 (TKWh)

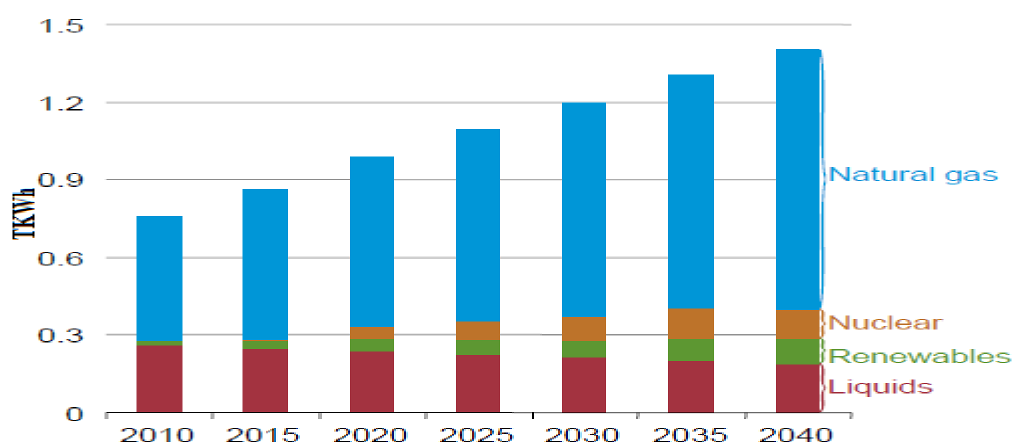


Figure 1.5: Middle East net electricity generation by fuel, 2010-2040 (TKWh)

According to Saudi Electric Company, electricity generation for the Kingdom of Saudi Arabia was 220 TWh in 2011 [SEC, 2011]. International Energy Agency's key world energy statistics 2013 reported that KSA used oil to produce 142 TWh of electricity generation, second largest after Japan in 2011 making oil as a primary fuel source for electricity generation. In KSA, electric energy consumption is growing faster than GDP, leading to an increase in the total energy intensity (1.8 percent/year, on average, between 2000 and 2011) [SEC, 2011], which is contrary to the general trend observed in most countries. The electrical energy end use in KSA is maximum in the buildings sector (residential commercial and governmental) accounting for 76% of the total consumption. Heating Ventilation and Air Conditioning (HVAC) accounts for almost 70% (SEEC, 2012) of the total electricity consumption in buildings due to its extensive usage for maintaining thermal comfort. Air conditioning alone is responsible for 52% of the electricity consumption in KSA. The statistics show an ever-increasing demand for energy, especially in the building sector, thereby advocating the need for energy conservation.

The Saudi Arabian energy & environmental sector are encountering strain and the building`s role is more critical in comparison with the global levels. The related ecological burdens are said to increase in the near future as the construction industry is experiencing rapid growth. For instance, while around two-third of the population is less than 30 years old, evaluations propose that in order to provide the growing population with shelter, the country needs to construct 2.32 million new homes by 2020 [SCDSI, 2015]. Thus, the country is facing a rapid growth in energy demand much of which comes from the building sector.

Meeting the growing energy demand in a sustainable and socially responsible ways is among the best of approaches that may take into consideration any of the available renewable/sustainable strategies thereof. One of such innovative approaches to increase the energy efficiency of buildings is to install a rooftop of vegetation known as a Green Roof. It has the ability to provide a wide range of sustainability and ecological benefits while often enhancing the aesthetic qualities and architectural creativity of buildings.

This research seeks to explore the viability of green roof as a passive design strategy for reducing the energy usage of residential buildings in hot humid climatic conditions such as the one prevailing in the eastern province of Saudi Arabia. The thesis has strong simulation dimensions. The performance of the developed green roof will be compared against that of the conventional roof through a detailed energy modeling exercise using state of the art software tool (design builder). Economic analysis of the green roof will also be undertaken.

1.1 Problem statement

The quests for energy conservation in order to successfully increase the energy efficiency of buildings is growing. Green Building Council's, Leadership in Energy and Environmental Design (LEED) program and other green building initiatives are looking for a strategy to minimize the energy consumption and negative environmental impact of buildings on the ecosystem in a sustainable and socially responsible way. The rapid economic growth and the need for new residential buildings to meet the needs of growing population indicate a steep rise in energy demand in future. The situation implies enormous energy and environmental challenges for the country. Meeting the growing energy demand in a sustainable and socially responsible way is among the best of approaches that may take into consideration any of the available sustainable strategies thereof. One of such innovative approaches to increase the energy efficiency of buildings is to install a rooftop of vegetation known as a Green Roof. Green roof has the ability to provide a wide range of sustainability and ecological benefits while often enhancing the aesthetic qualities and architectural creativity of buildings. However, there has been inadequate research concerning green roof`s use in KSA. Literature search reveals that green roof's feasibility and energy saving potential has not been adequately researched in a more widespread setting to identify the relevant benefit and/or barriers.

1.2 Objectives of the Study

The main objectives of this study are as follows:

1. Undertake a modeling analysis with the state of the art simulation software tool to analyze the energy performance of a reference roof on a KFUPM single-family detached residential building.
2. Investigate the energy and environmental impacts of green roof considering the selected building as case study.
3. Undertake a cost benefit analysis of green roof.

1.3 Significance of the Research

The proposed work is aligned with the Saudi government's recent initiatives to improve the energy and material performance of buildings by providing adequate insulation to a building, which is a set criterion for connecting electricity (SEEC, 2014). It will help promote sustainable practices in the building sectors and will benefit teaching and research activities in the concerned research area. It will focus on performing design optimization with the required and necessary data using a wide range of green roof options in reducing energy consumption on a reference single-family detached home.

1.4 Scope and Limitation of the Research

This research aims to explore green roof as a solution for reducing the energy usage in residential buildings. The methodology includes literature review, building energy simulations and validation of developed models. It will explore the viability of green roof to provide an efficient solution in energy reduction for residential buildings in a hot humid environment. However, the thesis research will be limited to a residential building with a regional design trend at King Fahd University of petroleum and minerals KFUPM faculty housing in the city of Dhahran, Saudi Arabia.

1.5 Methodology of the study

The study plans consist of five main phases; these phases provide scientific approaches to achieve the objectives of the research, described as follows:

1.5.1 Phase 1: Literature review

- Investigate the energy demand for the single-family detached reference residential building.
- Review literature to identify the best international and local practice for design
- Examine variables that influence energy and environmental impacts of buildings.

1.5.2 Phase 2: Formulation of Base Model and Simulation

- Collection of required building characteristics of relevant sources and identification of related base case model development parameters
- Use of an appropriate simulation tool to model the selected building as base case for the green roof using a reliable data from KFUPM weather station.
- Validation of the base case model using data derived from the field.
- Simulation runs for verification of the base case model.

1.5.3 Phase 3: Green roof Strategies and Analysis

- Customization of the green roof according to the local weather data.
- Simulation of a conditioned residential building with the identified parameters.
- Performing design optimization with the required and necessary data using a wide range of green roof options

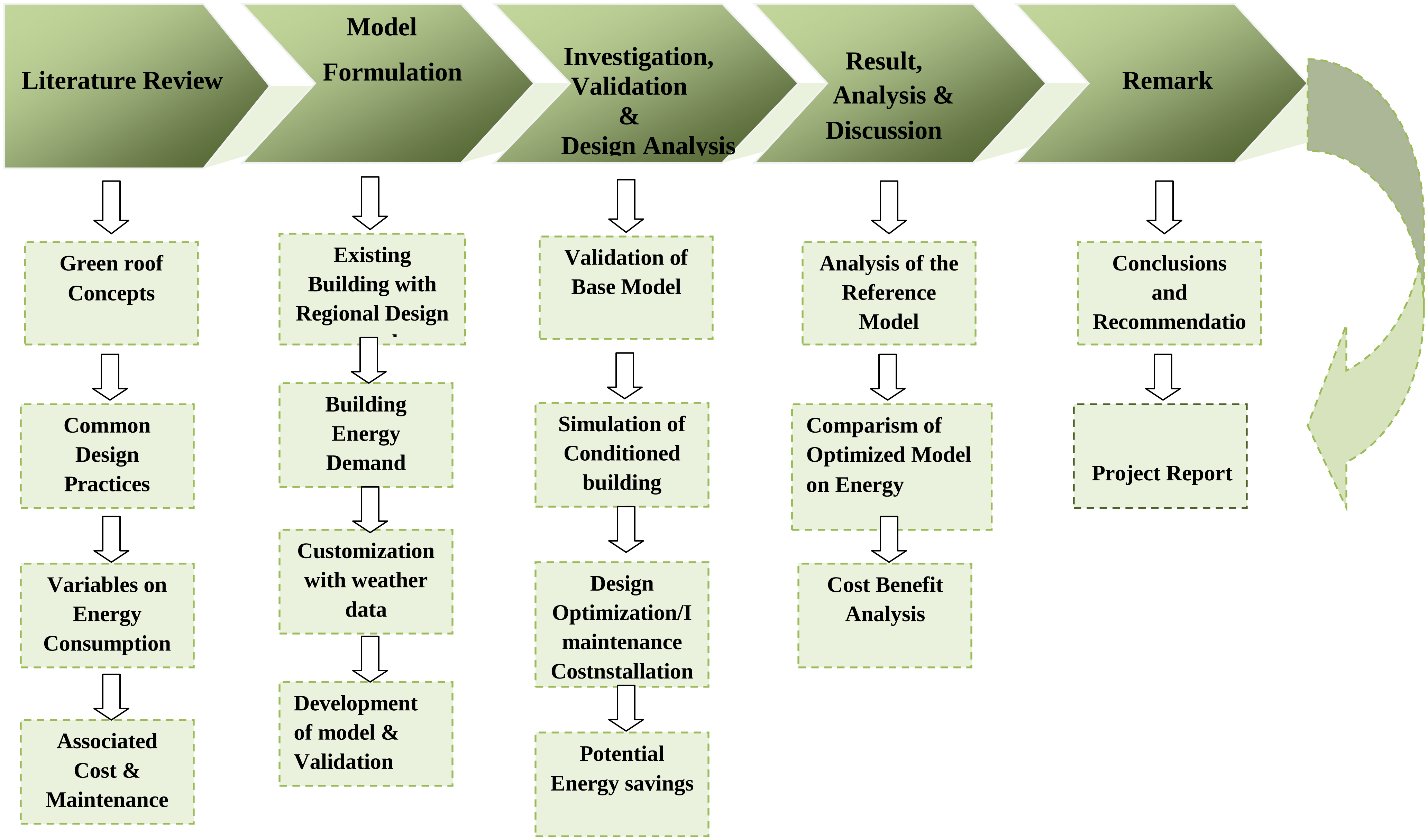
- Investigate the energy saving potentials of green in hot humid climate for a reference residential building

1.5.4 Phase 4: Result and Analysis

- Evaluation of the different green roof options to determine the most efficient one on energy reduction.
- The performance of the energy efficient enhanced roof is compared against that of the conventional roof through a detailed energy analysis.
- Performing cost benefit analysis of efficient green roof models

1.5.5 Phase 5: Conclusion and Recommendations

- Present the conclusions with regard to the achievements of the research work and the future work.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CHAPTER TWO

LITERATURE REVIEW

2.0 The building envelope

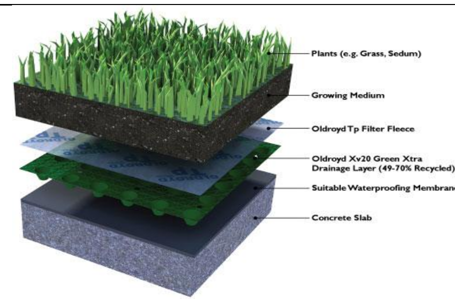
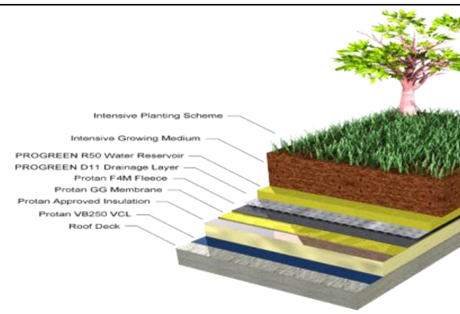
The building sector has a crucial relationship with the global energy and environmental scenarios as it accounts for almost one third of the global energy used and nearly 40% of the resources consumed [SBCI, U 2009]. A number of studies have explored the direct and indirect ecological effects from the development and operation of buildings. As indicated by (Alnaser *et al,* 2008), for instance, the yearly normal effect of the building sector includes energy use of 42%, atmospheric emissions of 40%, raw materials use of (30%), water use 25% Similarly, in the United States the commercial and residential buildings represent 40% of the annual energy use, more than other sectors. Energy requirements are increasing in line with population growth and globalization effects, electricity generation facility development is not in pace with the demand so, efforts were being made worldwide to conserve energy resources and to optimize the utilization of energy. One such direction is to reduce the collective impacts during the life cycle of the building. Conserving energy is one of the strategies and is unquestionably of great importance, since we rely on energy for everything we do. The building envelope is an important contributor to energy efficiency, responding to heating, cooling, ventilation, and natural lighting needs. In this scenario, materials with high evapotranspiration and high thermal emissivity for building envelope applications represent effective passive technologies for the reduction of the energy requirement for cooling [Synnefa *et al,* 2012].

In recent years, there has been a strong realization in Saudi Arabia for a reduction in energy consumption, and the building sector has the best capability of reducing energy demand in comparison to other significant sectors. As reported by the Saudi electricity eompany (SEC), energy consumption is growing faster than the gross domestic product (GDP), leading to an increase in the total energy intensity (1.8 percent/year, on average, between 2000 and 2011). In KSA, the building sector accounts for approximately 76% of the total electricity use, out of which the residential sector accounts for about 51% [SEC, 2011]. Several factors have contributed to the existence of inefficient buildings in the Kingdom, among others, include construction boom, cheap price of electricity, limited awareness of energy efficient strategies, and lack of policy compared to most advanced countries.

2.1 Green Roof Overview

Green Roof is roof top having planted vegetation on the roof surface or portion of a rooftop planting system that allows sustained presence of live plant, [Cooling Los Angeles a guide 2005]. It incorporates the planting of vegetation on the building rooftop, green Roof are categorized into types, extensive and Intensive, extensive green roof employ a low growing means of five inches or less, the plant generally includes succulent and moss, the aim is geared toward low maintenance and partial irrigation, roughly twice a year with no access to the roof for recreation [Jaffa *et al*, 2012]. Intensive green roof was characterized by its variety of vegetation ranging from herbaceous plants to small trees with professional maintenance and irrigation systems, typical growing medium depth of an intensive green roof is 6 inches or more and require higher nutrient applications and focused maintenance (GRT, 2014).

Table 1.1: Comparism between Extensive & Intensive Green Roofs System

	EXTENSIVE GREEN ROOF	INTENSIVE GREEN ROOF
EXAMPLES		
Objectives	For thermal insulation, fire proofing, suitable for retrofit, min. Weight	Max. Thermal performance, aesthetic, increases living space, suitable for new projects
Maintenance	Low maintenance	Usually high require the same maintenance as a garden on normal ground level
Thickness of planting medium	Normally between 2-20cm	20cm or more
Cost	Relatively cheap between per \$100-300/m2	Usually very expensive \$200 and above
Irrigation	Require little or no irrigation	Often requires irrigation
Plant communities	Usually ground cover	Accommodate biodiversity of plant species
Accessibility	No access for recreation and other uses	It supports a variety of activities related to recreation

2.2 The origins of green roofs

The basis of using green roofs can be trace back to the Ancient World around 500 B.C. The well-known green roofs were the Hanging Gardens of Babylon (Semiramis) and it was considers as one of the Seven wonders of the world, they were constructed over vaulted stone beams and waterproofed with layers of reeds and deep tar, Plants and trees was planted. This provides protection from the elements, good insulation during the winter months, and a cool location in the summer [Jamie Cutlip, 2006].

In various parts of the world, a green roof is well established, especially in Europe (Germany, UK, and Australia) and is also fast growing in North America and part of Asia; however the efficiency of green roof is greatly affected by the climate [IGRA, 2013]. The philosophy of green roof is to reduce the total direct and diffuse radiation incidences on the roof [Kohler et al 2002]. Green roofs not only provide insulation for energy savings, but also modify the temperature fluctuations experience by the roof membrane, thereby reducing the thermal stress and heat aging of the roof membrane thus elongating the life span [A.Teemusk and U. Mander, 2010]. Building with vegetation on roof top altered the relative humidity and solar radiation around [Saadattian et al 2013]. Thus, annual energy consumption as a result of the vegetated rooftop has a decreased and improved thermal comfort where the climate is characterized by high temperature and solar irradiance values during the day [A. Palla et al 2010]. Energy savings derived from green roof are directly related to the low cost of maintaining indoor climates that is heating and cooling [Issa Jaffal et al, 2011]. Findings of a research that monitored block apartment with sedum and peanut installed as thermal insulation in warm and humid climate of Hong Kong show significant energy reduction for sedum than peanut (C.Y Jim, 2014). An environmental and economic benefit of the green roof has also increased the energy efficiency and sustainability of the building [Issa Jaffal et al, 2011].

The other option use mechanical mean to hoist the plant that is already sprouting, the growing medium is prefabricated off site, this provides a better alternative to blocking for the latter can easily be removed if a leaching or maintenance issue should occur [Jamie Cutlip, 2006]. Comparism of two roof system with vegetated and no vegetation was carried out in 9 cities including Riyadh, analysis of energy performance of a building fabric with no consideration to interior thermal heat gains and losses, the result shows that the U-value is altered significantly for the conditions with vegetation leading to a decrease in the cooling load. Riyadh with a climatic condition of desert experience a higher cooling load decrease of about 90%. [Ouldboukhitine *et al*, 2011]. Simulation was carried out using an experiment in Athens to certify an investigative model using TRNSYS software and the result shows that in the case of retrofitting without insulation (U-value up to 1.99 w/m^2) but with moderate insulation (U-value u)to 0.8an annual reduction) with an annual reduction of 48% and 7% respectively in energy consumption [Orazio *et al*, 2013]. Green roof installed in school under Mediterranean climate show significant reduction up to 6-49% [santamori M, and Paulov C. 2009]. Reducing the surface temperature, thereby decreasing the cooling load by 32-100%, however, the amount of cooling load provided by the green roof through evapotranspiration will depend greatly on the climate and design management of the green roof [Farrell *et a,l* 2012]. Another simulation was carried out in Germany to determine the reduction in surface temperature by installing green rooftop, two types of roof were compared green and non-green roof the result shows a significant reduction of surface temperature and improved indoor climate under the green roof system, Studies in Athens, Greece has proven that, the hotter and drier a climate is, the more beneficial a green is in tackling urban heat temperature. Similarly the study conducted by a group of scientist in Singapore, discovered that green roof could reduce the surface temperature by 7.3℃ and thus is decreased by 0.5℃ compared with a bared roof during the day [Qin *et al*, 2012].

Green roofs have long been established and proven to provide economic, energy savings, and visual comfort [Monterusso *et al*, 2005].The efficiency of the green roof in expanding the benefit depends on the nature and the substrate layer [B. Dvorak and A. Volder, 2012]. Vegetation layer is the aesthetic layer of green and perhaps as a symbol of an environmental friendly product [E. Alexandria and P. Jones, 2008]. Investigation in Singapore has demonstrated that the substrate layer with clay is able to increase the thermal resistance of the roof by 0.4m^2k/w for each 10cm increase in thickness [Wong *et al*, 2003]. Change in physical characteristic of plant influence their environmental contribution [A. Nagase, N. Dunnet 2010]. Plant survival in hot and dry climate in providing the required benefit will depend on the availability of irrigation [S. Sheweka, N. Mohamed 2012]. Plant were exposed to different treatment i.e. watering and non-watering, the result shows that divers plants mixed was more advantageous than a monoculture in terms of greater survivability [E. Alexandria and P. Jones, 2008]. A study comparing five different plant species (Sedum pachyphyllum,S. clavatum, S. spurium, Disphyma crassifolium and Carpobrotus modestus) exposed to different drought treatment, i.e. watering and non-watering reveals that divers plants mixed are more advantageous than a monoculture in terms of greater survivability [Farrell *et al*, 2012]. Considering the geographical location of the climate under study, the effects of storm water management is inevitably not applicable, however, research has proven that vegetated roof are able to reduce storm water management by 40 percent, depending on the local climate of the region [9], a research in Singapore, reveal that with maximum intensity of rainfall that is 1mm/min the green roof was able to reduce the peak flow by 65% and retaining the overall runoff by 11.6% [Qin *et al*, 2012].

The philosophy of green roof is to reduce the total direct and diffuse radiation incidences on the roof [Kohler *et al,* 2002]. Green roofs not only provide insulation for energy savings, but also modify the temperature fluctuations experience by the roof membrane, thereby reducing the thermal stress and heat aging of the roof membrane thus elongating the life span [A. Teemusk and U. Mander, 2010]. Another study conducted in Jordan to examine the effects of green roof on energy consumption of HVAC systems in building indicates a total energy savings of 17% [Goussous *et al*, 2014]. Similarly, findings of a work comparing green roof and the conventional roof system in Egypt, with an arid climate, suggest the economic benefit of green roof system with varying annual energy savings between 15-32% depending on the soil thickness and the thermal conductivity of soil. [Kamel *et al*, 2012].

2.3 Saudi Energy Efficiency Program

Generally, the buildings (residential, governmental, and commercial) in Saudi Arabia are characterized with severe excess of electrical usage, whether in air conditioning, lighting, equipment, and other devices, as buildings consume 80% of the electricity produce in Saudi Arabia, whereas air conditioning represents 50% of this consumption. According to the annual report 2011, Electricity & the Cogeneration Regulatory Authority, consumption in the Buildings Sector for participants' categories and levels of their consumption reached more than half of the sold electricity. Saudi Arabia energy consumption was divided as follows: residential sector: 51.2%, commercial sector: 13.6%, governmental: 13.4%. Report of Ministry of Water and Electricity for the year 2011 on the total electricity energy sold to the residential sector revealed that it reached 109.261 gigawatt/hour, i.e. approx. 50% of the total energy sold in the Saudi Arabia. While a study conducted by the Electricity & the Cogeneration Regulatory Authority displayed that the residential sector consumes more than half of the electrical energy in the Saudi Arabia, where air conditioning loads represent 70% of the consumption. However, with the realization of the possible energy efficient techniques, governmental agencies are necessitating to minimize electricity consumption in the existing buildings, and use thermal insulation in the new buildings.

2.4 Challenges facing energy efficiency of buildings in Saudi Arabia

1. 70% of residential buildings are thermally not insulated (http://www.seec.gov.sa/)
2. Lower electricity bills
3. Low level of awareness of efficient energy products.
4. Low product control standards, for instance, currently there are no specifications, standards, or mechanisms to control insulation and lighting products.

2.5 Energy Saving Potentials of Green Roof

An experimental study for green roof was conducted in Athens to certify an investigative model using TRNSYS software and the result shows that in the case of retrofitting without insulation (U-value up to 1.99 w/m^2) but with moderate insulation (U-value up to 0.8 w/m^2) with an annual reduction of 48% and 7% respectively in energy consumption . Green roof was install in a school under Mediterranean climate, it report that significant energy reduction was realised up to 6-49% [Fioretti *et al*, 2010]. However, the amount of cooling load provided by the green roof through evapotranspiration will depend greatly on the climate and design management of the green roof [A. Nagase and N. Dunnet, 2010]. Another simulation was carry out in Germany that compared greened and non-green roof, the result shows a significant reduction of surface temperature and improved indoor climate under the green roof system, Studies in Athens [Synnefa, A. *et al*, 2012]. The hotter and drier a climate is, the more beneficial a green is in tackling urban heat temperature. Similarly the study conducted by a group of scientist in Singapore, discovered that green roof could reduce the surface temperature by 7.3$^{\circ}C$ and thus is decrease by 0.5$^{\circ}C$ compared with a bared roof during the day [Qin e*t al*, 2012].

Research has link that an average of 20℃ were observe on the temperature difference between planted roofs and surfaces of the conventional roofs [Teemusk *et al*, 2010]. Hotter and drier climate show greater ability of reducing urban heat temperature when the buildings were covered with vegetation [Erica *et al*, 2007]. Annual energy consumption of vegetated rooftop has a decreased and improved internal comfort where the climate is characterized by high temperature and solar irradiance values during the day Environmental and economic benefits of the Green Roof have also increased the energy efficiency and sustainability of the building [Fioretti *et al*, 2010]. Energy savings derived from green roof relate to the low cost of maintaining indoor climates [Saadattian *et al*, 2013].

The efficiency of the green roof in expanding the benefit depends on the nature and the substrate layer [Dvorak and Volder 2012]. Vegetation layer is the aesthetic layer of green and perhaps as a symbol of an environmental friendly product [Alexandria and Jones 2008]. Investigation in Singapore has demonstrated that the substrate layer with clay is able to increase the thermal resistance of the roof by 0.4m^2kW for each 10cm increase in thickness [Cheong *et al*, 2003]. Change in physical characteristic of plant influence their environmental contribution [Nagase et al 2010]. Plant survival in hot and dry climate in providing the required benefit will depend on the availability of irrigation [Sheweka *et al*, 2012]. 5 Plant species (*Sedum pachyphyllum,S. clavatum, S. spurium, Disphyma crassifolium and Carpobrotus modestus)* were exposed to different drought treatment, i.e. watering and non-watering the result shows that divers plants mixed was more advantageous than a monoculture in terms of greater survivability [Mitchell *et al,* 2012]. Research has proven that vegetated roof are able to reduce storm water management by

40 percent, depending on the local climate of the region [Libbra, A. *et al*, 2011], a research in Singapore, reveal that with maximum intensity of rainfall that is 1mm/min the green roof was able to reduce the peak flow by 65% and retaining the overall runoff by 11.6% [Qin *et al*, 2012].

2.6 Green Roof System Components

Green Roof is composite covered structure [Fioretti *et al*, 2010]. The mechanism of Green Roof occurs where the soil is hauled on top of the roof where planting occur straight on top of the waterproof covering [Salah-Eddine *et al*, 2011]. Normally above this layer membrane is the root barriers, a drainage layer is next (with plastic profile element) design to take the surplus overspill to roof gutters & to store water for the plant in waterless season, next a sieve fabric is installed to prevent soil from washing away and compromising the drainage layer as water drains from the roof, finally the growing plant completes the Green Roof [Beattie, D. and Berghage, R.2004]. The other option use mechanical means to hoist the plant that is already sprouting, the growing medium is prefabricated off site, this provides a better alternative to blocking for the latter can easily be removed if a leaching or maintenance issue should occur [Jaffal *et al*, 2012]. However, the function of each layer must be fulfilled by some component in the green assembly. The decision included in the determination of each of these layers makes every a variety in the Green Roof. By and large, the main two layers, vegetation and growing medium, are considered in the order of Green Roof, while alternate layers are chosen to help this living portion of the Green Roof. A critical philosophical difference between Green Roof material and the conventional system is often made by the designer, Green Roof contain particular segments intended to protect the roof drainage system, while certain extraordinarily adjustable parts, for example, channel extenders to suit the expanded thickness of the Green Roof profile must be considered in the detail of the roof drainage system [Osmundson, T. 1999]. Roots and natural matter must be kept from hindering drainage pathway. In any situation, Green Roof frameworks are viewed as increments to the essential material of the conventional system needed to keep a building dry.

2.7 The Impact of Design Variables on Energy Consumption

2.7.1 Color of the roof and walls

Many building researches present that the color of the roof and walls have an important impact on the energy efficiency of residential buildings. [Ram Pandit *et al*, 2010] The effects of building envelope color on thermal performance of buildings depend on various parameters include; the composition of the wall, the orientation of the building, the attribute of windows and the modes of ventilation.[Cheng et al 2005]. Many researchers indicate that reflective roof and wall color can minimize the amount of solar heat that transmitted to the building and this will reflect in the amounts of energy uses. [Givoni and Hoffman 2010] tested different exterior colors on small buildings. It was discovered that wall that were painted white are 3.0OC cooler in the summer when compared to similar buildings with gray paint. Another investigation was carried out in Delhi, with black and white buildings were compared. It show/tell about that air temperatures within the white building was 4-8oC cooler than the black building during midsummer conditions, depending on the level of ventilation [Danny S & Perker 1995]. There are also many experiments that the thermal performance of roofing, the most important properties in the thermal performance of roof systems are the total solar reflectance and the infrared emittance Of course a roofing system designed to reduce cooling loads, this roofing system should have a very high solar reflectance (rejects solar radiation) with a very high infrared emittance (easily gives off any collected heat). Solar reflectance and infrared emittance testing of the roofing material samples was performed by DSET Laboratories, and the test results for the shingle samples are given in next table; [D S Perker *et al*, 2000]

2.7.2 Insulation

Insulation is the most important determinant of energy savings without the compromise of thermal comfort. The surface of building envelope is exposed to the exterior environment and poses greater risk of heat gain or loss depending on its thermal properties. Thermal insulation is a material that reduces this risk thereby reducing heating and cooling loads. As walls and roof together form almost an integral part of building envelope, the potential for heat gain or loss is usually high and thus the envelope needs to be thermally insulated. As a part of passive strategy, a technical report reviewed and summarized the state of understanding of enclosures with higher values of thermal resistance (Straube and Smegal, 2009). High R-value enclosure was defined as the one that attempts to bring exceptionally good control of heat flow through walls, roof, windows and foundations. This could be achieved only when the enclosure has high R-value insulation installed within the respective assembly. The requirements that define a high R-value enclosure include thermal continuity/thermal bridging, airtightness, durability, quality of construction, comfort and, economic aspects. Thermal continuity of insulating material reduces the risk of thermal bridging by avoiding the increased rate of heat transfer. Airtightness of a building needs to be increased when thermal insulation with increasing values is used in the envelope. Likewise durability, quality of construction, comfort and economic aspects hold their positions in defining a high R-value enclosure. Thermal insulation retards conductive, convective and/or radiative heat move, ASHRAE 2001). Insulation is considered as the most important determinant of both energy savings and indoor thermal comfort. When installed properly within wall and roof assemblies, reduces heat transfer and thermal bridges. Selection of appropriate insulating material for application takes into account climate of interest, environmental impact, IAQ impact, level of thermal resistance, its benefits other than insulating, cost-effectiveness, specific heat capacity, fire resistance, noise reduction, density, etc. The insulation is effective only when the structure of the building is air tight and without any leakages. More importantly, the insulation itself should not have cuts in between. Hence, a continuous insulation is usually preferred. If the insulation is not continuous, it entails thermal bridging thereby allowing heat to transfer inside the envelope. As the selection of insulation is climate specific, consideration must be given to the placement of insulation where water vapour comes into picture based on the thermal properties of moist air

Many studies described the energy savings by using appropriate wall and roof thermal insulation. A study was done by Chulsukon (2002) in Bangkok, Thailand (hot and humid climate of), the study showed 3-4% annual energy savings from light-weight walls with R-11 batt insulation and from cement tile roof with R-11 batt insulation. A similar study has been done, by Rasisutta and Haberl 2004) in the study, the authors investigated energy saving in house with different installation of thermal insulation on roof, the energy saving was a 9 % reduction on with R-10 interior insulation and 8% of total energy reduction with R-10 exterior insulation. Kootin-Sanwu 2004) conducted a similar study for house in the hot-humid climate of Central Texas, the results of the study indicated that a small annual electricity savings, but a high cooling energy savings in the summer for insulated Roofs

2.7.3 Thermal mass

Thermal mass plays important roles in energy cost reduction in buildings through reduced HVAC system size due to shifting peak load conditions and reducing the overall heat gain or loss. The concept behind thermal mass is the ability of the mass of the envelope to absorb heat and release the same as required. This is called as thermal lag and is achieved as a result of the time taken by a material to store heat and later release it. The placement of thermal mass varies with orientation for different climates, mass located on south is most efficient for heating application in some climates. Location of thermal mass is best at the ground floor as it absorbs and releases heat easily. Like thermal mass, now-a-days increased importance is being given to phase change materials as well Rasisuttha and Haberl (2004) stated that more energy saving from concrete block walls with thermal insulation on inside the wall than high thermal mass walls (8-inch and 12-inch brick walls). These researches showed that for a house with HVAC system not operating continuously; interior insulation provides more energy savings than thermal mass only, in order to achieve the desired temperature in a short time, higher savings from thermal mass expected in a house with HVAC system operating continuously.

2.7.4 Infiltration

Air infiltration has an important impact on the energy consumption of buildings. [46]. Infiltration is the uncontrolled event by which air leaks into building space. Infiltration can occur through seams in windows, doors or ductwork, through open chimneys, cracks, or any other part of a building envelope that is not seal tight. There are two primary causes of infiltration, and their relative importance depends on the type of building in question. In buildings that are less than three stories high, the primary cause of infiltration is usually windy. Wind blowing on the sides of a building induces a pressure gradient across the building envelope. This pressure gradient can drive air into the building on the windward side and out of the building on the leeward side, and can result in huge energy losses. In taller buildings, the main reason of infiltration is the stack effect [Emmerich, S *et al*, 1998]. Estimated the energy use in U.S. Office Buildings due to infiltration also they investigated the potential for energy savings that could be realized by envelope tightening efforts. These studies were done on 25 buildings located in different cities throughout the U.S. The outcome of this research predicted that infiltration is responsible for about 15% of the total heating energy and 4% of the total cooling energy for U.S. office buildings. Results also indicated that potential energy savings on the order of 26% for heating load and 15% for cooling load could be realized by tightening building envelopes by 25% to 50%.[Liu, m. 1992] Proposed that there are different -air infiltration energy consumption- calculation methods were developed by different authors, he State that Anderlind gave the most logical air infiltration energy consumption expression:

$$Q_{inf} = RMC_P(T_r - T_a)$$

Where

Q_{inf}= air infiltration energy consumption (W)

R = multiplier, which varies from 0 to 1 according to the structure of the wall with R approaching 1 for concentrated flow and zero for diffuse flow.

M = air infiltration rate (Kgls)

C_p = specific heat capacity of air (J/Kg C)

T_r = room air temperature (°C)

T_a = outside or ambient air temperature (°C).

2.7.5 Lighting

Design with climate is always beneficial. Orientation as the first step in the design strategy has been helpful in many areas including lighting. An appropriate building layout and orientation reduces the need for electric lighting and improves occupant comfort. A good lighting design is the one that provides balanced lighting levels. This could be achieving with the help of multiple window orientations. Lighting design considers the following: primary function of the space, type of lighting required, occupancy and style and placement of windows with respect to the path of the sun. There cannot be a house without artificial lighting these days. The use of compact fluorescent lamps (CFLs), more energy efficient light bulbs, automation techniques, smart technologies, dimmer switches and motion detectors\ help to reduce lighting energy consumption. Another strategy that minimizes the use of artificial is paint. It makes the spaces look bright and reduces heat gained into the space because of artificial lighting.

2.7.6 Humidity and its effect in buildings

Humidity in residential buildings has a great effect not only on the comfort and health of occupants, but also on durability of the coatings and the form of these buildings. Condensation of water contained in the air occurs when the relative humidity reached a limiting value known as saturation. Condensation can appear in the form of droplets in suspension in air (fog) or on a cold material support. The presence of fog in a residential building is rare. It is confine in specific parts and over short periods related to the occupational activity. Natural or mechanical ventilations are intend to fight efficiently against these internal contributions. Condensation on a material support occurs when the temperature of this one is lower than the air dew point temperature of the zone. This case worries the designers by the degradations involved in the spot. The caused disorders are generally deteriorations of the interior coatings (yellowish, black spots and then separation of paintings). Phenomena of corrosion of the metal structure can appear in the event of cracks in the coating. The hydrous transfers depend on the following phenomena [Franck Lucas, *et al*, 2002.]

2.7.7 The water vapor diffusion through a wall

The Water vapor diffusion through a wall mainly describes by the difference of partial pressure of vapor on both sides of the wall and the permeability of material following the law:

$$\varphi = -\pi \ \frac{dpv}{dx}$$

$\varphi =$ Mass flow rate (kg/m2 s)

$\pi =$ Mass flow rate (kg/m2 s)

$pv =$ Vaper pressure (Pa)

This equation provides the base form of the many wall design methods such as Dew point method, Glaser diagram (Trechsel, 2001). The objective of these methods is to evaluate the possibility of condensation of the water vapor during its migration through the wall. These methods are intend for the study of the wall in steady state conditions. In moderate climates, as the building is more often heated, the migration of vapor is from outside to inside.

2.7.8 Surface condensation

In general, roof surface condensation occurs when the temperature of a roof is lower than the dew point temperature,

$$\eta_{v\ cond} = S_{\varphi\ cond}$$

$$\eta_{v\ cond} = \text{Vapor mass flow (kg/s)}$$

$$\varphi = \text{ Mass flow rate (kg/m2 s)}$$

The rate of vapor condensation depends on the difference in partial pressure of vapor between the air of the room and the air on the surface of the roof and can be expressed by:

$$\varphi_{cond} = \omega\ (p_{v\ air} - p_{v\ surf})$$

$$\omega = 7.4 \times 10^{-9}\ h_c$$

Where, for walleyes has = 1.079 $\Delta\ T^{\ 0.33}$

$$P\ \mathrm{v}_{air} = \frac{H}{100} P\ \mathrm{v}_{air,\ sat}$$

$$P\ \mathrm{v}_{air,\ sat} = 140974 \times 10^{5} \exp\left(\frac{-3928.5}{Tair + 231.667}\right)$$

$$P\ \mathrm{v}_{air,\ surf} = f(T_{surf}) = 140974 \times 10^{5} \exp\left(\frac{-3928.5}{Tsurf + 231.667}\right)$$

$\boldsymbol{H}$ Relative humidity (%)

$\boldsymbol{P}$ Pressure (Pa)

$\boldsymbol{T}$ Temperature (k)

$\boldsymbol{\omega}$ Humidity ratio (kg/kgdryair)

2.7.9 The hygroscopic behavior of materials

Hygroscopy is the capability of a substance to pull in and hold water particles from the surrounding environment through either ingestion or absorption with the adsorbing material getting physically "changed," to some degree, While some comparative power are at work at this point, it is not the same as capillary rise, a procedure where glass or other "strong" substances draw in water, yet are not changing the whole time, e.g. water particles getting to be suspended between the glass atoms. Most simulation tool disregards the hygroscopic conduct of building materials. However, sometimes its standout as the most paramount variables in moistly exchange in rooms (Franck Lucas, et al, 2002)

2.7.10 Orientation

Orientation always plays a crucial role in building design. It helps gain access to effective utilization of solar energy depending on geographic coordinates and earth's axis. As sun rises in the east and sets in the west another worthy consideration in this regard is the alignment of the home along the east-west axis. The conductive heat flow must be restricted in order to improve the thermal performance of the envelope. This could be achieve by considering the form factor of the building, which in other words is called as the building shape. Shapes that are complex in nature leak energy by exposing more surface area of the envelope to the exterior environment. Thus, a compact design of the envelope should be utilize to minimize surface area thereby reducing heat gain or heat loss potential. The compactness should be as close to square as possible to minimize corners. As window-to-wall area ratio (WWR) was studied to design a window for a particular orientation, the floor-to-envelope area ratio should be studied to maximize floor area in relation to envelope area.

An ideal elevation must be selected to incorporate the windows. East and west elevations have large values for heat gains compared to south. Heat transfer is at its peak when the angle of incidence of solar radiation is at its minimum. An advantage with the south elevation is that windows on south do not experience minimum angle even when sun rises or sets compared to its east and west elevation counterparts. This makes the south elevation an attractive choice. For climates witnessed in Saudi Arabia, solar gain is a big concern and strategies need to be employed to reduce it. The southern elevation can be utilized by increasing WWR area ratio compared to east and west elevations. In addition to this, appropriate external shading devices should be designed that help reduce solar gain in summer and allow direct solar gain in winter when the sun is low. The eastern and western elevations can have minimum WWR to reduce solar gain in summer. The north elevation does not experience direct solar gains and can be utilized for daylighting.

2.7.11 The airflow transfers

Air flow happens between building envelopes and outside with our building diverse zones. The principle purposes behind air flow are pressure difference that is distinct between two points and the opening joining these meeting points. (Straube, 2001) there are three primary reasons that depict the control of air flow in building performance. Moisture control – water vapor in the air can be deposited within the envelope by condensation and cause serious health, durability, and performance problems

Energy savings –air leaking out of a building must be replaced with outdoor air, which requires energy to condition it. Approximately 30% to 50% of spaces conditioning energy consumption in many well-insulated buildings are due to air leakage through the building enclosure. Convective circulation and wind washing both reduce the effectiveness of thermal insulation and thus increase energy transfer across the envelope.

Comfort and health – cold drafts and the excessively dry wintertime air that results from excessive air leakage directly affect human comfort, wind-cooled portions of the interior of the enclosure promote condensation which supports biological growth, which in turn affects indoor air quality, airborne sound transmission control requires better airflow control, and odors and gases from outside and adjoining buildings often annoy or cause health problems.

(Straube, 2001) Illustrate that there are three primary mechanisms which generate the pressure differences required for air flow within and through buildings:

1. Wind,
2. Stack effect or buoyancy, and
3. Mechanical air handling equipment and appliances.

The air flow with outside or with the other zones intervene in the moisture balance of the zone in the form (Franck Lucas, et al, 2002)

$$\mathfrak{m}_{vaeraul} = \mathfrak{m}_{v_{as}} (w_{ae} - w_i)$$

$\mathfrak{m}_{v\,aeraul}$ Vapor mass flow (kg/s)

w_{ae} outside air humidity ratio (kg/kgdryair)

WI Subscript of the zones, humidity ratio (kg/kgdryair)

2.7.12 Contributions due to the occupants

The releases of vapor due to the occupants and their activity plays a major role in the energy use for residential buildings and the impact of such factor is unknown, a study from Netherlands shows that significant energy use up to 4.2% from occupant activity. However, some occupant behaviour and culture may affect the overall energy consumption (Santin O. *et al,* 2009). The load appears in the moisture balance of the zone in a term giving the vapor generation rate. (Franck Lucas, *et al*, 2002)

2.8 Roof Systems Performance in Hot –Humid Climate

Geometry largely determines the degree to which the roof system will affect the overall energy balance of a building. The higher the ratio of roof area to building volume, the more significant heat transfer through the roof assembly becomes. The Oak Ridge National Laboratory (Griggs, Sharp, & MacDonald, 1989) stated that the roof can comprise 50 to 75% of the building's total envelope in a typical one-story building, making the roof's thermal properties critical to the building's energy performance. The faster heat transfer takes place, the more the building must rely on other systems to maintain temperatures within the comfort zone. Typically, this calibration is achieved through the use of energy-consumption heating and air conditioning systems, incurring considerable installation and operating costs to the building owner and environmental costs to local and global ecosystems

2.9 Benefit of a Green Roof

[Erica O *et al*, 2007, Teemusk A *et al*, 2010]. Green roofs offer economic, environmental, and societal benefits for the individual building and the wider urban environment. These benefits range from stormwater management impacts on local infrastructure to amenity benefits for building occupants and the community.

These benefit is been categorizes into the main green roof installation, focusing on the following areas:

- Energy Conservation
- Biodiversity and habitat
- Urban heat island
- Urban agriculture
- Acoustics
- Air quality
- Aesthetics and quality of life
- Job generation and economic development
- Roof longevity

2.10 Energy and Environmental Benefits

2.10.1 Green Roof & Energy Conservation

Comparism of a two roof system with vegetated and no vegetation was carried out in 9 cities including Riyadh with different climatic conditions, analysis of energy performance of a building fabric with no consideration to interior thermal heat gains and losses with an average U-value, Ti (indoor temperature and Tout (outdoor temperature) was observe with the relationship as:

$q_{e[gr-a]}$ = U ($T_{[gr-a]-}$ T_{in}). For both wall and roof vegetated

$q_{e[no\ gr]}$ = U ($T_{[no\ gr]\_-}$ T_{in}). For conditions with no green vegetation

The result shows that the U-value is altered significantly for the conditions with vegetation leading to a decrease in the cooling load. Riyadh with a climatic condition of desert experience a higher cooling load decrease of about 90% [Alexandria E et al 2008] Another study with DOE-2, energy simulation and numerical analysis were used to establish the effect of roof top vegetation on the yearly energy expenditure and cooling load, compared with that of a soil on a roof top, R-values & U-values were determined. Surface temperature was measured at different level, with three species of plants of different succulence or foliage to examine the effects of temperature reduction resulting from the foliage.

Thus the rate of heat flow per unit area is estimated

$q_1 = \frac{1}{ER} \Delta T$

$q_1 = (\frac{1}{Rp+Ro})(t_{1-}t_2) = (\frac{1}{Ro})(t_2 - t_3)$

Note: RP thermal resistance of vegetation, Ro thermal resistance of roof construction and soil

The calculated R-values of turfing, shrubs and trees are: 0.36, 1.61 and 0.57 m^2KW

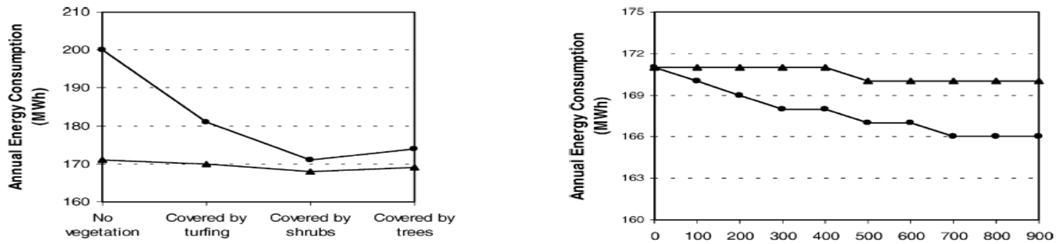


Figure 2.6: Annual energy consumption

The result revealed that installing Green Rooftop gives a savings of 15% in the annual energy consumption, 79% in space cooling load and 79% of peak space load, the most advantageous rooftop vegetation is the roof top with shrubs [Wong N H et al 2003]

similarly simulation was carried out using an experiment conducted in Athens to certify an investigative model using TRNSYS software and the result shows that in the case of retrofitting without insulation (U-value up to 1.99 w/m^2) But with moderate insulation (U-value up to 0.8 w/m^2) With an annual reduction of 48% and 7% respectively in energy consumption [Orazio et al 2012], Green Roof installed in school under Mediterranean climate show significant reduction up to 6-49% [Fioretti R et al 2010] cited from santamori M, Paulov C. Reducing the surface temperature, thereby decreasing the cooling load by 32-100% [Saadattin O et al 2013], heat transfer and their capability of reducing energy consumption, However, the amount of cooling load provided by the Green Roof through evapotranspiration will depend greatly on the climate and design management of the Green Roof [Monterusso M A et al 2005] resource guide, a study was carried out in three different climatic zones and the result revealed that that the total energy demand in all the three studied climates of 12.8kWh/m^2 Yearly (32%) for Mediterranean climate of Athens, 2.3kWh/m^2 (6%) for temperate climate and 10.7kWh/m^2 (8%) for cold climate attached table, the technology was proficient to reduce the energy consumption and attenuation of surface temperature fluctuations [Sala-Eddine et al 2011]. Another simulation was carried out in Germany to determine the reduction in surface temperature by installing Green Rooftop, two types of roof were compared greened and non Green Roof the result shows a significant reduction of surface temperature and improved indoor climate under the Green Roof system, Studies in Athens, Greece has proven that, the hotter and drier a climatic is, the more beneficial a green is in tackling urban heat temperature

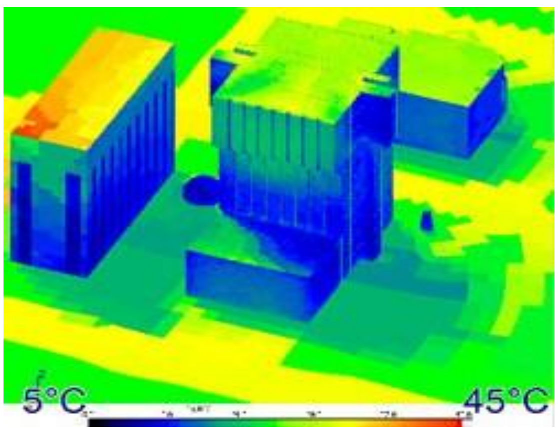


Figure 7.2 thermal imaging of conventional & Green Roof

Air temperature at roof level is between 26℃ maximum and 12.8℃ day time in Riyadh [Alexandria E et al 2008]. Similarly the study of group of scientist in Singapore, discovered that Green Roof could reduce the surface temperature by 7.3℃ and thus ambient air is decreased by 0.5℃ compared with a bared roof during the day [Qin X et al 2012]

2.10.2 Lower ambient temperature: Reduction of Urban Heat Island Effect

At the beginning of the twentieth century, 15% of the world population lived in cities. Currently, about 50% of the world population lives in urban areas, which is approximately 2.8% of the total land of our planet, (Millennium Ecosystem Assessment, 2005). The increase in urban inhabitants has led to urban sprawl, especially in developing countries (United Nations, 2014). It is often associated with the rise in urban temperatures (Tabares-Velasco, PC and Srebric, J. 2009.), the so-called urban heat island (UHI) effect Under hot and arid climates, roof temperatures reach almost 70^{o}C and about 50% of heat enters into buildings through roof slab (Vardoulakis et al 2014). During summer, city temperatures are approximately 5-7^{0}C higher than in the countryside. This is because buildings and roads in urban areas absorb and subsequently emit heat (thermal mass). This phenomenon is called the ‘Urban Heat Island’ effect [Susca, T., Gaffin, S.R., and Dell’Osso, G.R. 2011]. Research carried out by the Tyndall Centre for Climate Change shows that we need 10% more greenery in towns and cities in order to counteract climate change Many studies established the correlation between an increase in green areas and a reduction in local temperature (e.g., Takebayashi and Moriyama, 2007 Roofs constitute about 20–25% of the urban surface (Akbari et al., 2003). Their urban-wide conversion into green roofs can give rise to many benefits both on urban scale – effects on UHI, air quality, storm-water management, biodiversity and urban amenities (Oberndorfer et al., 2007) Green largely reflects heat thereby creating a lower ambient temperature. Furthermore, plants cool the air because they emit moisture. As cities have limited space for parks and gardens, green roofs offer an ideal means to bring about more greenery in the city. (Source: ‘Groen boven alles’ (Green comes first), Energy Savings Monitor

2.10.3 Reduction of carbon footprints: capture of CO_2

There is a consensus among climate scientists that global weather patterns are changing, with some regions getting hotter and drier, while others will become wetter [Yang, J., Yu, Q. and Gong, P. 2008]. One of the highest contributors to human-induced climate change is the built environment. Within the built environment, the biggest land use type contributing to greenhouse gas emissions is the residential sector Carter & Fowler, 2008]. While efforts are being made globally to improve sustainability in buildings through operational and embodied energy-efficient design, most of the stock that will exist by 2050 is already here.

CO2 is a gaseous substance created mainly through the combustion of fossil fuels. The amount of CO2 in the air has increased significantly since the industrial revolution. This increase is considered one of the most important causes of global warming. It is common knowledge that plants absorb CO2. Unfortunately, CO2 emissions have not increased at the same rate or been compensated by a steadily growing number of trees and plants. We do not yet know how much CO2 Sedum can capture, but because of the large number of succulents per m2 the amount is expected to be considerable. Green roofs help to reduce CO2 in the air, and subsequently global warming. Factory and vehicle emissions has contributed a lot in destroying the ecosystem which provide humane environment for living, however vegetation are capable of reducing the air pollutant in the environment if passes over the plants, foliage or leave index can also absorb the gaseous pollutant, but the effect is much pronounce on intensive green roof with trees and shrubs than extensive roof system [Dunnet & Kingsbury 2004] Urban habitat Values can be achieve through the green roof system which provide habitat for birds and insects thereby promoting indigenous species

2.10.4 Mitigation of air pollution and enhanced urban air quality

Fine particles in the air are one of the greatest dangers to public health. They cause heart problems and aggravate pulmonary diseases. The National Institute for Public Health and the Environment (RIVM) in the Netherlands has calculated that every year 18,000 people in the Netherlands suffer a premature death due to short-term exposure to fine particles. 1.5 kilos of fine particles per hectare Elements in nature can trap fine particles, which then flow into the sewer system along with the rainwater. Extensive green roofs capture an estimated 1.5 kilos of fine particles per hectare. This more or less corresponds with the capture capacity of one adult tree. So a green roof captures more fine particles than a smooth bitumen roof without Sedum. This is because of the irregular structure of the surface. The more irregular the surface the more fine particles that are captured, Cities typically suffer from high levels of exhaust fumes. Therefore, green roofs have a positive effect on air quality and the reduction of fine particles in the air. A 10%-20% increase in the number of green roofs in a city will substantially contribute to the health of the inhabitants. [6,8,9]

2.10.5 Rainwater retention: Less burden on sewer system and fewer ensuing floods

As a result of global climate change, heavy rainfall is now a more common occurrence. A major advantage of green roofs is that they help to reduce the burden on sewer systems. new buildings are required to withstand heavy downpours. In recent years more rivers have overflowed their banks and have flooded stretches of land than ever before. This often causes huge economic and environmental damage. Water retention on roofs is becoming increasingly important, especially in densely populated countries. 70%-95% less burden on sewer system Research shows that green roofs significantly reduce the amount of water that flows into the sewer system, between 70% and 95% in summer. The plants and substrate of the green roof store rainwater which then evaporates straight back into the atmosphere. The amount of water that can be stored in a green roof depends on the thickness and type of substrate, type of drainage and vegetation. Research has proven those vegetated roofs are able to reduce storm water management by 40 percent depending on the local climate of the region [Tonietto, Fant, Ascher, Ellis, & Larkin, 2011]. a research in Singapore, reveal that with maximum intensity of rainfall that is 1mm/min the green roof was able to reduce the peak flow by 65% and retaining the overall run off by 11.6% [Ksiazek, Fant, & Skogen, 2012]. At least 8-10 Euros savings per m2 the amount of rainwater that is collected can be quantified by the amount of water that is processed. We can compare this to the costs of measures taken for processing rainwater via other means than via the sewer system. The average costs amount to 15 Euros per square meter. An extensive green roof will process approximately 54% of the rainwater in winter. So the savings come to 54% of 15 Euros, which amounts to at least 8 to 10 Euros per square meter.

2.10.6 Rainwater purification: Cleaner environment

Green roofs not only retain huge amounts of rainwater, they also purify the water, The rainwater first flows through the plant and substrate layers before reaching the drain, thus purifying the water. Research carried out by [Kohler & Schmidt 2000] shows that 95% of the lead, copper and cadmium sulphide and 19% of the zinc that falls on the roof via the rainwater remains in the substrate. The percentage of nitrogen is also substantial, but more difficult to quantify.

2.10.7 Ecological preservation of natural habitat for birds and insects

Wherever buildings are constructed, microhabitats are usually disrupted. Green roofs help to re-establish these microhabitats, and help to restore the ecological cycle. Green roofs provide an important refuge for microhabitats in urban areas. Green roofs in urban centers provide other benefits such as mitigation of urban heat islands, reduced energy use, reduced air pollution, enhanced storm water management, and the creation of natural habitats for animals and plants (Clark, Adriaens, & Talbot, 2008; USGSA, 2013). You can stimulate biodiversity by choosing the correct amount of substrate, and having a large variety of plants. According to research conducted in Switzerland and England, green roofs can even provide a habitat for rare insect species. Green roofs in large cities have high potential as habitat for species negatively impacted by land-use changes (Brenneisen, 2006). Although green roofs support a lower abundance of invertebrate than nearby urban green space (Brenneisen, 2006; Gedge & Snep, WallisDeVries, & Opdam, 2011), green roofs can be designed to mitigate habitat loss for insects and wildlife in urban areas (MacIvor & Lundholm 2011]

2.10.8 Increase in Building Roof life Span

Although the initial money needed to set up and care for green roofs are high, but they are advantageous in the extensive run, the philosophy of green roof is to reduce the total direct and diffuse radiation incidences on the roof [16] Green roofs not only provide insulation for energy savings but also modify the temperature fluctuations experience by the roof membrane thereby reducing the thermal stress and heat aging of the roof membrane thus elongating the life span [24

2.10.9 Sound absorption & insulation

Green roofs can reduce noise pollution from airplanes, elevated transit and traffic, particularly for low- and medium-frequency waves. They have better noise reduction per unit of weight than traditional or concrete roofs. This reduction will primarily affect a building’s top floo**r**. Green roofs can enhance the attenuation of diffracted sound and reduce the transmission of sound through a buildings’ roof, particularly in buildings without additional ceiling insulation. According to extensive studies, roofs 2 to 6 inches thick have reduced the noise level of a roof by 8 decibels or more, depending on the water content in the growing medium. The greater the proportion of a roof covered in green roofing, the greater the reduction in sound pressure from noises traveling across the roof. The weight of a roof determines the amount of insulation available to attenuate surrounding noise. The texture of growth medium can affect this attenuation. Green roofs have the potential to reduce both low frequency sounds (blocked by the growing medium) and high frequency sounds (blocked by the vegetation).

The growing medium, drainage layers, and vegetation determine the weight of a roof, and therefore the amount of insulation thereby available to attenuate surrounding noise.

2.11 Green Roof Policies and Examples

2.11.1 Germany

During the oil crisis of the 1970s, Germany discover lightweight adaptations of sod roofs for the reason of energy conservation, that created a adopted because of its wide range of ecological benefits and interdisciplinary study that led to the technological principle, many German cities are now covered with Green Roofs, building guiding principle are adopted and such legal law had an encouraging sound effects toward the wide increase realization of Green Roof technology, by 2005, an estimation of 13.5 million square meters m^2 roof area in Germany were covered with vegetations. [Erica O et al 2007] Councils and local authorities grant direct financial support for the Green Roof project, which varies from 25-100% of the material and installation cost [IGRA, 2013].

Figure 2.8: Extensive green roof, Geno Haus Germany

In UK there are no incisions policies regarding the implementation of Green Roof, however the Mayor and Boroughs should encourage the use of living roof were the opportunity arise, its widespread throughout UK for some factors often related to growing interest and is believed to have 300% growth toward Green Roof industry, Green Roofs play a vital role in helping the Mayor's target to boot Green Roof cover in central London by 5% by 2030. They can develop the city's resilience to the impacts of climate change by reducing the total storm water run-off and helping to keep buildings, sustainable. Largest Green Roof technology was installed on the new Rolls Royce factory in Chichester (40,000m^2) Public awareness, increase and a lot of schemes had been adopted to include Green Roof on their buildings [IGRA access 01-05-2013, Urbis Limited 2007]

Figure 2.9: Rolls-Royce 40,000 sqm of green roof

Figure 2.10: N H Pri. Sch. 350 sqm intensive roof top roof in Chichester

2.11.2 United State of America

The square footage of Green Roof in the US grew by 28.5 percent according to the annual industry survey by Green Roof for healthy cities (GRHC), government investment in green for their storm water, air quality green space and city cooling benefit largely fuels the development of the Green Roof industry, Chicago had the most Green Roof with more than 500,000 square feet installed, Washington DC was a close second other are New York, Seattle and Philadelphia, Portland building that are 500 square feet of waterproof are mandated to reduce storm water contamination and run rates allowing a developer an extra square feet that covers a least of 60% of the roof it continues to lead the way with incentives and regulation that recognize the benefits [IGRA access 01-05-2013, motherearthnews access 11-04-2013]

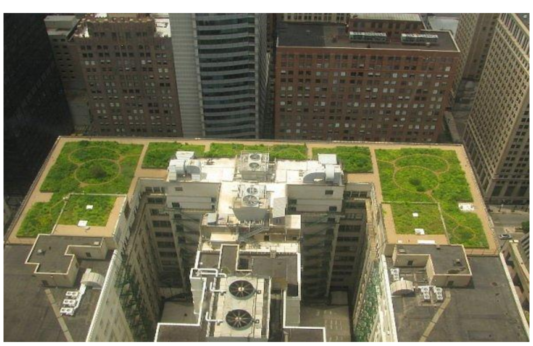


Figure 2.11: Chicago, Illinois extensive roof

Figure 2.12: 6500sqm intensive park tower condominium

2.11.3 Tokyo, Japan

Japan began with an informal incentive programs that provide a free consulting service this was followed by a subsidy program which resulted to7000sqm of roof green built Concern over environmental impacts on the buildings had necessitated the government to adopt a policy that any new building projects bigger than 10,000 and public buildings larger than 25,000 square feet must endow with 20 percent of the roof surface to be developed as vegetation or pay an annual penalty[motherearthnews access 11-04-2013]

CHAPTER THREE

COST BENEFIT ANALYSIS

3.1 Life Cycle Cost Analysis

Life cycle cost analysis is an economic method of project evaluation in which all costs arising from owning, operating, maintaining and disposing of a project. Moreover, is a tool to determine the most cost-effective option among different competing alternatives to purchase, own, operate, maintain and, finally, dispose of an object or process.

Energy conservation projects provide excellent examples for the application of cost analysis, there are abundant opportunities for improving the thermal performance of envelope components e.g. wall, roof, windows in both new and existing buildings to reduce the heat loss in winter and heat gain in summer, providing acceptable comfort conditions throughout the year at a cost effective energy efficiency may require life cycle analysis to determine whether or not these projects are economically justified based on reduced energy cost and other cost implications over the projects life. A better accounting of the green roof's total costs and benefits to society and to the private sector will aid in the design of policy instruments and educational materials that affect individual decisions about green roof construction.

Cost benefit analysis has been widely recognized as a useful framework for assessing the positive and negative aspects of prospective actions and policies, and for making the economic implications alternatives an explicit part of the decision-making process (Arrow 1996). Cost benefit analysis compares alternatives over time as well as space, and uses discounts to summarize its findings into a measure of net present value (NPV). The test of NPV is a standard method for assessing present value of competing projects over time. In the case of this study, the roofing scenario with the lowest NPV is the preferred option as the lower value indicates the least costly alternative.

3.2 Green Roof Cost and Benefits

There are many documented benefits of green roofs. They supply an otherwise dry region with thermal mass and evaporative cooling. Soil and plants also provide a natural insulation for the building structure, which aids in reducing energy use and minimizing utility costs for businesses. Soil and plants are used on the edifice absorb water, thus reducing storm water runoff. Green roofs also help reduce costs and the production of landfill-bound garbage by eliminating the use of petroleum-based shingles. Green roofs have numerous incentives for business owners as well. For example, many hotels have utilized green roofs to help with storm-water management, growing fresh produce for in-house use in restaurants, and for cutting costs because self-sustaining roofs require little to no maintenance (Cannarsa 2008). Aside from the environmental and economic benefits, green roofs are aesthetically pleasing, can help in promoting sustainable community gardens and in some instances can serve as additional city green spaces, as demonstrated by New York's High Line, a park built on an out of use railway in Manhattan (Friends of the High Line 2009).

3.2.1 Reduced Energy Use

Green roofs could reduce the energy needed to provide thermal comfort within the building. At the point when green rooftops are wet, they ingest and store a lot of heat, which decreases temperature variances. At the point when dry, green rooftop layers go about as a protector, diminishing the stream of warmth through the rooftop, in this manner decreasing the cooling vitality expected to decrease building inside temperatures. In the winter, this protecting impact implies that less warmth from inside the building is lost through the rooftop, which diminishes warming needs. In the mid year, green rooftop vegetation diminishes rooftop surface temperatures and surrounding air temperatures, hence bringing down the cooling vitality request. The protecting properties of green rooftops fluctuate as they are dynamic frameworks that change as the year progressed, especially with respect to water stockpiling. In the winter, this protecting impact implies that less heat from inside the building is lost through the rooftops, which reduce heat needs. In the mid year, green rooftop vegetation diminishes rooftop surface temperatures and surrounding air temperatures, hence bringing down the cooling vitality request. The protecting properties of green rooftops fluctuate as they are dynamic frameworks that change as the year progressed, especially with respect to water storage

Although green roofs could save energy both in summer season and in winter, those particular savings will rely on upon the atmosphere. Furthermore building features, for example, size, use, also encasing. Chicago estimates that its city lobby green top undertaking Might provide cooling savings for upto or take 9,270 kWh for every year Furthermore heating savings of 740 million Btus. This makes as annual, building-level energy savings for something like $3,600.[Chicago City Hall green roof project, 2014]

Canadian study demonstrated the heating and cooling energy investment savings of an approximately 32,000- square foot (2,980 m2) green rooftop on a one-story public building in Toronto. The investigation assessed that the green rooftop could save around 6 percent of aggregate cooling and 10 percent of heating energy use, or around 21,000 kWh all total. The study noticed that the cooling energy investment savings would be more noteworthy in lower scopes. Case in point, when the creators ran the same recreation for Santa Barbara, California, the cooling investment savings expanded to 10 percent. [Bass, B et al 2003]. Another study in focal Florida measured year-round energy savings from a green rooftop, by the rooftop's second summer, the normal rate of heat exchange, or flux, through the green rooftop was more than 40 percent not exactly for the nearby light-shaded rooftop. The decreased heat flux was generally assessed to lower summertime energy utilization of the 3,300 square foot (1,000 m2) venture by roughly 2.0 kWh every day [Cummings, J et al 2007].

Under winter heating conditions, when the open air temperature was less than 55°F (13°C), the heat flux was around 50 percent less for the green rooftop than for the conventional rooftop [Sonne, J. 2006] University of Michigan study, the cost of conventional rooftops with the cost of a 21,000-square-foot (1,950 m2) green rooftop and every one of its advantages, for example, stormwater management and enhanced general wellbeing. The green rooftop would cost $464,000 toinstall versus $335,000 for a conventional rooftop in 2006 dollars. Nonetheless, over its lifetime, the green rooftop would save about $200,000. About 66% of these savings would originate from decreased energy requirements for the building with the green rooftop [Clark, C et al 2007].

3.2.2 Costs of green roof

The cost of green rooftops differ depending upon the component, for example, the growing medium, type of roofing membrane, drainage system, use of fencing or railings, and type and quantity of plants. A 2001 report evaluates that initial cost at $10 every square foot (0.09 m2) for the less complex, extensive rooftop and $25 every square foot for intensive rooftops [Scholz-Barth, K. 2001]. A different evaluation assumes $15 to $20 every square foot. Cost in Germany, where green rooftops are more predominant, price ranges from $8 to $15 every square foot. Prices in the United States may be higher as business sector interest and builder experience increase. Initial green rooftop costs are more than those of most conventional and cool rooftop innovations. Green rooftops have a more extended expected life, however, than most material items, so the aggregate annualized operating cost of a green rooftop may be closer to those of conventional and cool rooftops. Los Angeles evaluated that to retrofit a building with a far reaching green rooftop would cost from $1.03-$1.66 every square foot, on an annualized basis, while a traditional re-material would extend from $0.51-$1.74 every square foot [City of Los Angeles (A Resource Guide).2006 Los Angeles, CA]. Because of the greater amount of layers and intricacy, intensive roofs require a higher capital investment ($25-40+/sq ft) and have higher long-term maintenance costs. Extensive green roofs are the lighter weight and simpler designed roofs that typically cost $5-$25/sq ft or $54- $269/sqm (EPA 2008). There are various factors driving costs which lead to the wide range of cost estimates. The design and specifications of a project, the type of existing roof, roof accessibility and the type of new roof system required in re-roofing with a roof-root-repelling membrane, green roof system (the type and depth of growing medium, square footage of the green roof), the types of plants and season of installation, installation and labor and maintenance costs (typically only for the first two years) are all factored in to the extensive green roof cost range. These factors are cost drivers for intensive roofs, with the addition of an irrigation cost component and higher and long-term maintenance costs (Peck, 2010).

A green roof installed on rooftop of Duke University Hospital building with a roof area equal to ~6000 square feet, cost $17 to $20/sq ft in roofing assembly, installation, which includes the price for the greening component, $8 to $10/sq ft (Pennigar 2011). Xero Flor America's pre vegetated mats were used in the green roof because they have a synthetic fiber in them, which makes it easy and inexpensive if a portion of the green roof needs to be replaced. The design of intensive roofs does not allow for such simplified and cheap installations and replacement options. The goal of an extensive green roof is to design a roof that requires little to no maintenance and added structural support. Extensive green roofs are less expensive and the preferred type when retrofitting an older building.

3.2.3 Maintenance of green roof

Whether extensive, intensive, or somewhere in between, green roofs generally consist of the same basic components, the cost of installation are discussed above, and from the top layer down these include: Vegetation, growing medium, a filter layer, a drainage layer, protective layer(root barrier, water proofing membrane, vapor barrier).

Notwithstanding, the construction costs of a building owner brings about maintenance expenses to care for the plants on a green rooftop. Despite the fact that the level of consideration relies on upon plant choice, the majority of the costs emerge in the first years after establishment, as the plants make themselves and developed. For a far-reaching rooftop, support expenses may run from $0.75 to $1.50 every square foot. The cost of keeping up a far-reaching rooftop diminishes after the plants cover the whole rooftop.

3.3 Cost Benefit Analysis Framework

The first category deals with construction and maintenance expenses. The construction costs of a typical built-up bituminous roof system on a concrete roof deck were taken from personal interviews with three staff from project department KFUPM, and a contractor. The conventional roof was assumed to have a 15-year guarantee on the waterproofing membrane and thus an effective 15-year life before replacement.

Tanyard Branch urban watershed in Athens, Georgia will be used as a basis for calculation and theory. The authors of the study Tanyard Branch combined the local construction costs for an established green roof test site with experimentally data and building energy analysis data into single metric using conventional cost-benefit analytical techniques applied over the life cycle of a typical green roof. The Tanyard Branch project, a 42.64sqm green roof test plot was established in October 2002 on the campus of the University of Georgia. The test plot was designed to be simple to build and easy to replicate using American Hydrotech's extensive garden roof. American Hydrotech's, Inc. is a single source supplier for the specialized green roofing materials.

These materials included a WSF40 root protection sheet, an SSM 45 moisture retention mat, a Floradrain FD40 synthetic drainage panel, and a System filter SF geotextile filter sheet (American Hydrotech's, 2002). The growing media was a Lightweight Roof Garden mix provided by It Saul Natural, LLC. This soil mix is a blend of 55% Stalite expanded slate, 30% USGA sand, and 15% organic matter composed primarily of worm castings. This mix was spread to a depth of 7.62 cm. Six drought-tolerant plant species were selected for their ability to survive low nutrient conditions and extreme temperature fluctuations found at the roof surface. No irrigation or fertilization was applied except for the initial three days of planting (Carter 2006).

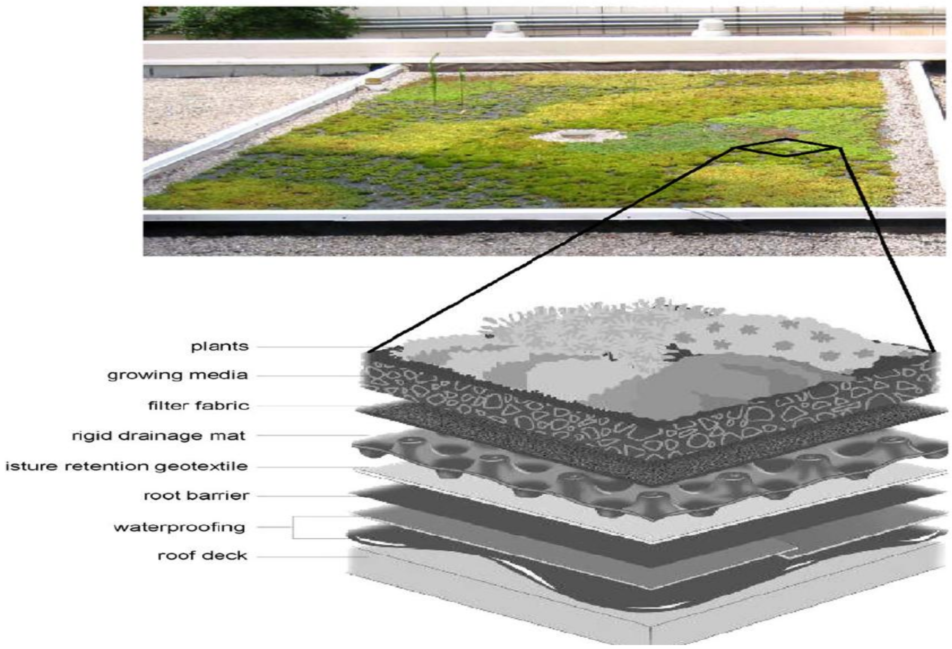


Figure 3.1: Green roof test plot and layer cross-section (Carter 2006)

The average cost of a unit extensive green roof is estimated at $158.82/m2, this is mostly at the high end of what will be experienced for widespread green roof construction in the Tanyard watershed. It is partially based on estimates of what would be required to build an initial demonstration roof, and thus ignores economies of scale in materials purchasing as well as innovations in construction techniques developed as local contractors gained experience. Second, in Germany, where the industry has been established for over 30 years, construction costs may be as much as 50% lower for larger installations.

3.4 Cost-benefit analysis of green roofs

Reliable development management requires quantitative appraisals of cost and benefit of the choice to the use of nature [Kosareo and Ries 2006], [Clark et al. 2008], [Carter and

Keeler 2007] have demonstrated the financial points of interest of green rooftops. Be that as it may be, a lifecycle benefit cost to a unit zone of a green rooftop is still not accessible. This part of write-up concentrates on filling the gap with best accessible information with rational hypothesis. Information identified with lifecycle cost benefit saving of green rooftops is to a great degree uncommon and basically subjective (hard to measure). The examination present in this section is taking into account a broad writing audit in numerous fields, for example, forestry, designing and plant science

3.4.1 Property value

Regular landscape benefits property holders and entrepreneur by expanding the business estimation of properties. There is no direct writing to note property worth increment because of green rooftops. The worth of a normal house could increase by 7.1% in the event that it is near to a forest spread (Garrod, 2002). The Council of Trees and Landscape Appraisers (CTLA, 2003) found that procurement of trees/greenery could add from 15% to 25% to the aggregate worth of properties. Moreover, the Commission of Architecture and the Built Environment (CABE, 2005) demonstrated that properties increase their value by 7% in areas arranged with trees. Green rooftops don't give the same advantages as forests and timberlands. Accordingly, this study conservatively considered that broad green extensive rooftops could increase properties cost by 1% to 3%. While, serious green rooftops expand may differ somewhere around 6% and 10%. The aggregate worth of a property relies on upon numerous reasons, for example, territory, area, structure sort or nearness to public services. This advantage was assessed as an increment at the beginning expense of green rooftops. Subsequently, for extensive green rooftops, the lower and higher value was expanded from 2% and 5%respectives. In essence, for serious green rooftops, the lower and higher starting cost expanded by 10% and 20%, separately. The assessment considered that extensive green rooftops increases property worth by 0.1 %. The cost of the reference building is estimated at SR 3, 000,000.00

3.4.2 Longevity benefit

The normal lifespan of green rooftop ranges from 40 to 55 years (Acks, 2005; Kosareo and Ries, 2006; Saiz et al., 2006; Clark et al., 2008), while the life of conventional rooftops is around 20 years (City of Portland, 2008). The reroofing expense of an ordinary rooftop is assessed as $160/m2 ($15/ft2) (City of Portland, 2008). in future, the property owner of the needs to pay this expense in like every 20 years. Since green rooftops have a higher lifespan than conventional rooftops, decreased cost of supersede a conventional rooftop which is considered as an advantage. In the event that the probabilistic examination (Monte Carlo) haphazardly chose a time period of 40 years, the expense of replacing was considered as $160/m2. Moreover, if the Monte Carlo reenactment arbitrarily chose a timeline of over 40 years, a property owner would need to replace the conventional rooftop not less than two times. In such a case, the advantage is evaluated as twofold of the advantage of one routine rooftop substitution. Subsequently, an advantage of SR2/m2 (for green rooftops) was utilized to gauge the NPV

3.4.3 Carbon reduction

Diverse kind of plants can be developed on green rooftops. By and large, Crassulacean Acid Metabolism (CAM) plants are favored due to their water preservation limit under dry conditions [Getter and Rowe, 2006]. Apparently, the oxygen-carbon dioxide conversion scale contrasts between plant species. Past assessment have demonstrated that

1 ha of green rooftops displace between 72 kg to 85 kg of toxins (Currie and Bass, 2005; Yang et al., 2008). The carbon decrease expense is assessed as $20/ton (Kyoto Protocol, 1997), in this way, this research considered that the yearly advantage of carbon removal charge at SR75/ton for every kind green rooftop.

3.4.4 Air quality improvements

Green rooftops have been acknowledged as an air contamination control innovation (Schnelle and Brown, 2002). Air quality is identified with the measure of dust, particulates, and nitrates (NO_2) noticeable all around (Peck et al., 1999; Carter and Keeler, 2007). The NOx losses acknowledge is evaluated as $3375/ton (Clark et al., 2005). Subsequently, considering the green rooftops air contamination removal extent depicted earlier, the enhanced air quality advantage would be around SR 0.094/m2 for any type of green rooftop

3.4.5 Habitat creation

Natural Environment creation and protection, is greatly imperative to relieve the unfavorable impacts of urban settings. The City of Portland (2008) contributed $275,000 per acre of land to buy and after that restore it as a natural environment. Green rooftops replace impenetrable rooftop top regions with plants and soil, which pulls in little creatures, for example, butterflies, winged animals, bugs, and honey bees. On account of 39 creepy crawlies, the developing medium in green rooftops can give a comparative natural surroundings to the environment ensured or restored in the city connection (Schrader and Böning, 2006). These features signify avoided expense; subsequently, it can be considered as a social advantage. It is imperative to note that green rooftops don't give the same level of advantages as natural environment. Subsequently, this investigation accepted that a suitable exchange of advantages would be 15% for an extensive. Natural surroundings creation is not a typical interest in numerous urban areas. In this way, advantages that range from SR2.5/m2 were utilized for reaching or getting the required habitat creation through the applied green roof.

3.4.6 Mitigation of urban heat island effect

Albedo is the reflection capability of any surface (Susca et al., 2011). Dim surfaces reflect less sun solar radiation. Consequently, take in more energy. Urban region have dark surfaces with low albedo, for example, cement and black-top. The blend of dull surfaces and absence of vegetation increase urban air temperature amid summer months (Rosenfeld et al., 1995). Temperature increase prompts an increment of energy demand because of the utilization of HVAC system. Akbari et al. (1992) have observed that urban electric demand in six urban areas in United States expanded from 2% to 4% for every 1°C rise in day by day operation most extreme temperature, over the limit of 15°C to 20°C. It is assessed that heat island effects increase electrical utilization by around 1 GW to 1.5 GW every year in the Los Angeles Basin (Akbari et al., 2001, Lee et al., 2007),). Los Angeles Basin has a zone of 1,212 km2 (United States Census Bureau, 2010); in this manner, the City's electrical demand differs between 0.83 kWh/m2 to 1.24 kWh/m2. Zinzi and Agnoli (2011) assessed that green rooftops save 10% to 14% of the electrical energy expended in cooling residential buildings. By considering the cost of power as SR0.26/kWh this investigation considers that green rooftops can lessen urban temperature, which is identified as an advantage, between SR 3/m2

3.5 Economic relevance of Energy and Insulation

The second economically relevant category is energy and insulation. Green roofs act to reduce the rooftop surface temperatures through leaf shading direct solar radiation, evaporation of moisture at the surface and transpiration of the plants which cool the ambient air above the roof. Thin layer green roof systems have consistently been shown to reduce the temperature fluctuations at the roof surface (Onmura 2001). Whether this translates into significant energy savings is not clear from the literature as in one study, energy use was evaluated for small experimental sheds containing green roofs and the vegetated treatments had little effect on total energy use in each structure (DeNard 2003). Other research, however, suggests that considerable energy cost savings can be realized when green roofs are used; enough for the life cycle cost of a green roof to be less than a traditional roof when energy savings were included in the analysis (Wong 2003). Assuming that more energy cost savings can be realized on buildings where the ratio of the foot print of the building to the volume of the building is greater.

For the energy-related benefits of the Tanyard Branch study, local data were used. Adjacent to the storm water green roof test plot, a second experimental roof was constructed and an analysis of the thermal conductivity of growing media as well as energy load modeling was performed. Automated measurement of in situ micro meteorological parameters such as humidity, air temperature, wind speed, radiation, and soil temperature were combined with laboratory analysis of the engineered growing medium providing local data for simulation modeling. The simulation programs used were eQuest and HYDRUS-1D, a building energy model and a combined heat and moisture simulation, respectively. The modeled buildings used were 929sqm with both square and rectangular orientations. Cost savings from the additional insulation provided by the green roof as well as the reductions in the heating and cooling loads were found for the building and converted into unit savings to be applied across the watershed. The green roof's insulating value was equivalent to R-2.8, which is similar to 2.54 cm of fiberboard, fiberglass, or perlite. These types of insulation average to $3.98/m2 and this value may be considered an avoided cost in the green roofing analysis. If this avoided cost is used, however, the building owner will not realize any energy savings as there is no net increase in insulation.

A more likely scenario is that the green roof will be added and provide additional insulation, not used as replacement for traditional insulation. This additional insulation value creates energy savings for the building owner. The authors used the building energy savings modeled from a single-story 929m2 building (Hilten, 2005). This type of building was selected because it represents the majority of flat-roofed buildings in the watershed. The energy load reduction from the green roof system was modeled at 4222.56kWh/year. This is an energy savings of 3.3% which is less than half of the 8% used in the Wong et al. (2003) study. Residential rate surveys for the 2005 year were acquired from the Georgia Public Service Commission and the 2005 average rate of $0.082/kWh was applied to the energy savings modeled in the building. This current price is used for the conservative base case BCA, but we believe that assuming electricity prices will remain constant in real terms over the next 40 years is extremely optimistic. The unit energy savings for current energy rates was $0.37/m2

Benefit	
Building energy savings (kWh/year)	4222.56
Energy cost ($/kWh)	0.08
Building energy savings ($/m^2/year)	0.37
Total annual savings in Tanyard Branch ($)	65,871.73

Figure 3.2: Energy benefits associated with green roof (Carter 2008)

CHAPTER FOUR

BASE CASE FORMULATION AND INVESTIGATION

4.1 Building Energy Modeling Program (BEMPPs)

Computer simulation is one of the most effective and economic methods to predict and analyze building energy consumption and performance (DOE, 2014). The simulation industry has developed rapidly since the1960s, with hundreds of Building Energy Modeling Programs (BEMPs) developed and used around the world. Well known BEMPs include HEED, EnergyPlus & DOE-2, ESP-r, TAS, TRNSYS, BEopt, ECOTECT, IES Virtual Environment, eQUEST and Design Builder.

Nowadays, designers need tools that answer to very specific questions even during the initial design phase. Through the use of energy simulation software designers can consider specific choices, (e.g, heating and cooling). Designers can also predict the thermal behavior of buildings prior to their construction and simulate the costs of energy in existent buildings in their current conditions, establishing the best thermal retrofitting measures to adopt in the buildings under analysis. Besides the energy consumption, simulation software tools can also be used to calculate to the following variables

A user friendly program interface is ideal to a non-engineering discipline while at the same time having sufficient detail necessary to conduct a research. Inter-software operability is also essential to take advantage of other software strengths through data sharable file formats. Exhibiting compliance with standards used for similar building performance studies is crucial for credibility. In determining the functionality and capability of a software, it is important to utilize an appropriate tool in performance analysis. There are several available software in the market with varying capabilities. Its features should be narrowed down using the researcher's user preference criterion

4.2 Building Performance Energy Simulation (BPES) Tools

In recent years, the variables affecting energy use have increased and understanding building behavior has become a discouraging task. However, technological advancements in computer software have provided tools that are more effective at predicting energy performance, once the building is operational. An energy simulation tool models the thermal, visual, ventilation and other energy consuming processes taking place within a building to predict its energy and environmental performance. During its calculation process, it takes into account the external climatic factors, internal heat sources, building materials and systems to accurately model the building. Building energy simulation is a powerful method for studying energy performance of buildings and for evaluating architectural design decisions as well as choices for construction materials and methods. Complicated design issues can be examined and their performance can be quantified and evaluated. Simulation and energy analysis are essential to designers in developing effective forms and components for their buildings. Building energy simulation is an analysis of the dynamic energy performance of a building using computer modeling and simulation techniques. Such tools support the integrated use of multiple investigation and visualization during the design evolution process from the conceptual and schematic phases to the detailed specification of building components and systems. Building energy simulation can also help facility managers and engineers identify energy saving potentials and evaluate the energy performance and cost-effectiveness of energy saving measures to be implemented. No matter which software is used, calibration of simulation models is necessary and crucial for the accuracy and usability of energy simulation. The calibration process compares the results of the simulation with measured data and tunes the simulation until its results closely match the measured data. Whole building simulation tools are widely used and are applied to the entire building as an integrated system; these take into account all parameters and components together.

4.3 Simulation Tools and Comparison

A large number of simulation tools have been developed over the last few decades. The building energy simulation software tool web page, run by the US Department of Energy lists over 240 tools, ranging from research grade software to commercial products. Some important studies and comparisons were previously done on some of these tools that are discussed below:

(Crawley, 2005) provides an overview of a report, which provides up-to-date comparison of the features and capabilities of twenty major building energy simulation programs. The comparison is based on information provided by the program developers in the following categories: general modeling features; zone loads; building envelope and daylighting and solar; infiltration, ventilation and multizone airflow; renewable energy systems, electrical systems and equipment; HVAC systems; HVAC equipment; environmental emissions, economic evaluation, climate data availability, results reporting; validation; and user interface, links to other programs, and availability.

(Neymark, 2002) stated that validation of building energy simulation programs consists of a combination of empirical validation, analytical verification, and comparative analysis techniques (Crawley, 2008) describe testing and validation of EnergyPlus. The results to date show good agreement with well established simulation tools such as DOE-2.1E, BLAST, and ESP-r. Several testing utilities have been developed to help automate the task of assuring that each new version of the software is still performing properly. Selected test results are presented along with lessons learned

(Zhou, 2008) evaluate the energy performance of the VRV air-conditioning system, a new simulation module is developed and validated experimentally in this study, on the basis of the building energy simulation program, EnergyPlus. The differences between average monitored and predicted data for the total cooling energy and power use are proved to be within 25.19% and 28.31%, respectively. Comprehensive testing of building energy analysis software is a difficult task given the infinite combinations of inputs that may be entered and the difficulties in establishing truth standards for all but the simplest cases. Testing has been guided by a comprehensive test plan which includes the following types of tests

A research contrasted the capabilities of building energy performance simulation programs (Crawley et al., 2008). An up-to-date comparison of the features and capabilities of the most used building energy programs was provided and was based on the following categories: general modelling features, zone loads, building envelope, HVAC systems, electrical systems & equipment, economic evaluation, environmental emissions, etc. The building energy simulation programs that were considered included BLAST, BSim, DeST, DOE 2.1E, ECOTECT, Ener-Win, Energy Express, Energy-10 EnergyPlus, eQuest, ESP-r, IDA ICE, IES <VE>, HAP, HEED, PowerDomus, SUNREL, Tas, TRACE and TRNSYS. Weytjens and colleagues compared six BPS tools based on the architect friendliness (Weytjens et al., 2010). The study was carried out concerning building energy to provide early design support for architects. The tools that were examined included ECOTECT, IES/VE – Sketch-Up, Energy10, eQuest, HEED and DesignBuilder. Certain criteria were set to define the user-friendliness of the tools. The results showed that no tool was entirely adequate for architects use. Worth noting here was the selection of DesignBuilder among the six tools for comparison. DesignBuilder provides a graphical user interface (GUI) to today's widely used energy simulation engine EnergyPlus. Another study compared different BPS tools for architect-friendliness based on online survey (Attia et al., 2009). The survey took into consideration ten tools and received 249 valid responses. Among the tools considered were ECOTECT, HEED, Energy 10, Design Builder, eQUEST, DOE-2, Green Building Studio, IES VE, Energy Plus and Energy Plus- SketchUp Plugin (OpenStudio). Two issues were set forth: Usability and Information Management (UIM) and Integration of Intelligent Design Knowledge-Base (IIKB) of the software tools. If was found that architects preferred IIKB over UIM in the tool's interface. Highest numbers of responses were from architects and designers and many were from LEED accredited professionals. It was noted that DesignBuilder was used by approximately 22% of the respondents. It was also considered as a tool that was used in early design phase by the respondents. The tools were grouped into three categories and results revealed that DesignBuilder was ranked in the second category with a slightly less agreement among the respondents for architect-friendliness even though it was popularly known to have friendly GUI and varied graphical output features.

A summary of the selection criteria of BPS tools based on architects‟ and engineers‟ perspective of the requirements of the tool was presented in a research publication (Attia et al., 2011).

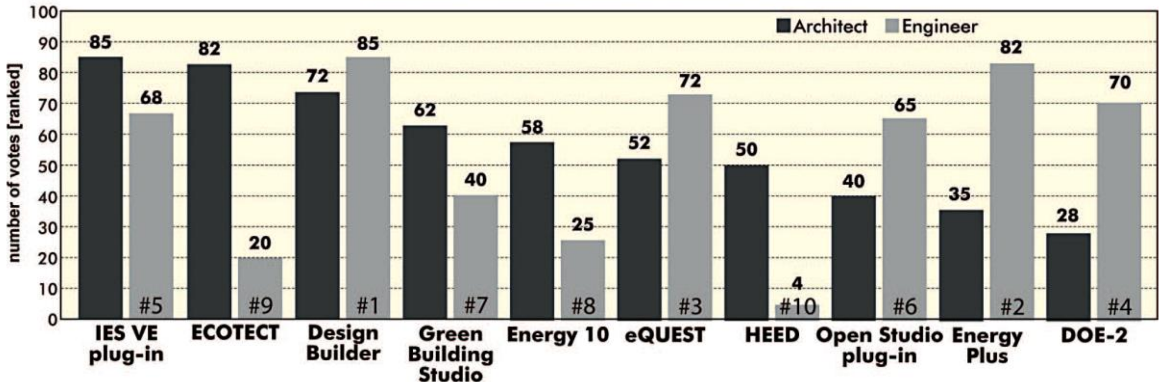


Figure 4.1: Architect Vs Engineers ranking (Reference: Attia et al 2011)

It might be possible that architect's requirements of a tool could be least important to engineer's requirements. Results indicated a wide gap in between architects‟ and engineers‟ requirements of the tool. It was found that the architects look for architectural design issues such as exterior shading, passive heating/cooling, natural ventilation, building shape and massing, etc in a tool. But engineers put in entirely a different perspective. They look for HVAC systems, controls, glazing options, insulation, etc. The comparison of "six" and "ten" BPS tools respectively in the aforementioned paragraphs discussed the architect-friendliness but not engineer-friendliness. This means that DesignBuilder which was slightly under-rated may be highly-rated by engineers depending on its functionalities.

The inclusions were TAS, TRYYS, e-Quest, DOE-2, DesignBuilder, ECOTECT, HEED, BEopt, ESP-r and IES-VE. The criteria sets were usability, intelligence, interoperability, accuracy, design process integration, general modelling features, Zone loads, Building envelope, HVAC systems, Electrical Systems & Equipment and Economic Evaluation. In order to better understand specific features of each one, Table below presents a summary of all the features of each of the software tools mentioned above. One needs to use a tool that is capable of simulating a wide variety of features for green roof. DesignBuilder provides such capabilities in a broader and detailed manner with the help of its energy simulation engine EnergyPlus.

Table 4.1: Comparison of Software capability

	TAS	TRNSYS	eQUEST	DOE-2	Design Builder	ECOTECT	BEopt	ESP-r	IES-VE
Green Roofs	x	x	X	X	X	X	X	X	X
Energy	x	x	X	X	X	X	X	X	X
Environmental (CO_2)		x	X	X	X	X		X	X
Economic	x	x	X	X	X		X	X	
Flexible use and navigation	x	x	X	X	X		X	X	X
Comfort & Climate		x		X	X		X	X	X
Climate Analysis	x	x	X	X	X	X	X		X
Comfort Visualisation	x	x	X	X	X	X	X	X	X
Geometry & Massing	x	x	X	X	X	X	X	X	X
Daylighting	x	x	X	X	X	X	X	X	X
Natural Ventilation		x	X	X	X				X
Thermal Mass	x	x	X	X	X	X	X	X	X
Shading Devices			X	X	X	X		X	X
Energy Efficiency	x	x	X	X	X	X	X	X	X
Envelope Insulation	x	x	X	X	X	X	X	X	X
Glazing Performance		x	X		X	X	X	X	X
Envelope Air Tightness	x		X	X	X	X	X	X	X
Artificial Lighting	x	x	X	X	X	X	X	X	X
Infiltration Rate	x	x		X	X	X	X	X	X
Mechanical Ventilation	x	x	X	X	X	X	X	X	X
Cooling System	x	x	X		X	X	X		X
Heating System	x	x	X	X	X	X	X	X	X
3D Spatial Analysis					x		X	X	X
Innovative Solutions & Technologies		x	X		X	X	X	X	
Short learning Period	X		X	X	X	X	X	X	X
Graphical rept. of input & Output data		x		X	X	X			X

4.4 DesignBuilder

DesignBuilder as mentioned earlier is a tool used in early design phase. It provides a GUI to today's widely used energy simulation engine EnergyPlus and is popularly known to have varied graphical output features. It has strong design features that address the design aspects of green roof especially the v4, that hold it good for carrying out parametric and performance based analyses. The strengths, weaknesses and data exchange capabilities of DesignBuilder illustrated that the simulation program had most comprehensive user-interface for the most widely used energy simulation engine EnergyPlus (Maile et al., 2007). The illustration was based on four grounds namely tool architecture & functionality, life-cycle usage, Cost benefit, data exchange & interoperability and limitations. Portrayed in a graphic was the information workflow in DesignBuilder. The workflow starts with selecting a location for carrying out the analysis. Then the tool allows the creation of building geometry and other definable parameters such as internal loads, construction types, windows, doors, lighting, material selection, HVAC systems, etc DesignBuilder even supports DXF file format to model the building using its footprint. It is appropriate for beginners as it provides help contents within its user-interface. DesignBuilder could be used in all phases of the design. It also provides modelling of more complex geometries that is difficult to achieve with other building energy Simulation tools. The major limitation that hinders the capability of DesignBuilder is the inability of the tool to import EnergyPlus input files. This therefore leads to the development of a geometric model separately. Thus, DesignBuilder is set for conducting the research activities.

4.5 Building Envelope Information

This section describes the specification of the building's envelope systems as provided by the contractor. This includes the information pertaining to walls, roof, windows and floor systems.

4.5.1 The wall System

The walls of the house have the following specifications: plaster (dense) as the outermost layer, concrete block (medium) on both side with thermal insulation sandwiched in between, and plaster (lightweight) as the innermost layer. The total thickness is 279 mm with an overall U-value of 0.466 W/m^2-K. (Project dept. KFUPM) The concrete blocks have been observed to be equal in thickness, however, the thickness of the plaster is varying depending on its placement in the wall assembly.

4.5.2 Roof System

The roof of the house has the following specifications: roofing concrete tiles as the outermost layer, high density polyethylene, thermal insulation, bitumen felt/sheet, cement screed, and reinforced concrete (dense) as the innermost layer. The total thickness is 403.2 mm with an overall U-value of 0.539 W/m^2-K.

4.5.3 Window System

The windows of the house are of the sliding panel / fixed glass plate type in an aluminium frame without thermal break. They are double glazed with two glass layers sandwiching the air layer. Glasses are light tinted and the thickness of the two glass layers is different. The total thickness is 22 mm with an overall U-value of 2.71 W/m^2 K.

4.5.4 Floor

The flooring system of the house is a slab on grade. It has the following specifications: glazed ceramic tiles as the outermost layer, cement mortar, dense reinforced concrete, high density polyethylene, and sand as the innermost layer. The overall U-value is calculated to be 0.792 W/m^2-K.

4.5.5 H.V.A.C System

This section describes the features and a specification of the building's cooling systems. This includes the information pertaining to the capacity (tonnage), supply air and outside air requirements, and temperature set-points of constant-volume direct expansion air-conditioning units. Each floor is served by the one unit thus requiring two units for the whole house. The cooling system for the ground floor is higher in capacity, supply air, and outdoor air requirements whereas the cooling system for the first floor is comparatively lower in every aspect. Depending on the type of climate observed at the location of the housing, the humidity control is considered as dehumidification where the hot-humid air is first cooled to get rid of moisture and then slightly heated for supply. The systems are not equipped with heat recovery or any energy efficiency measures. The air definition into each zone is based on the outside and supply air requirement.

4.5.6 Equipment Information Summary

This section describes the specifications of the equipment used in the house in terms of power requirements.

Table 4.2: Equipment Specifications (project dept. KFUPM)

S/No.	Description
1	Refrigerator/Freezer
2	Microwave
3	Cooking Range (electric stove & extract hood
4	Washing machine
5	Clothes dryer
6	TV
7	Vacuum Cleaner

4.6 Dhahran Climate

Dhahran is located at latitude 26°16'N, longitude 050°10'E, and with elevation of 17m. The Dhahran's climate is characterized by extremely hot, humid summers, and cool winters. Temperatures can rise to more than 50 °C in the summer, coupled with extreme humidity (85-100 RH percent), given the city's proximity to the Arabian Gulf. Dhahran holds the record for the highest dew point ever recorded in the world. On July 8th, 2003 the dew point was 35 °C. The air temperature at the time was 42 °C giving a heat index of 78 °C. It also holds the record for the highest temperature recorded in the country 51 °C In winter, the temperature rarely falls below 2 °C or 3 °C with rain falling mostly between the months of November and May. The Shamal winds usually blow across the city in the early months of the summer, occasionally also bringing dust storms that can reduce visibility to a few meters. These winds can last for up to three months. (Wikipedia, 2011)

4.7 The University Faculty Housing

The building is a single family 4-bedroom faculty housing designed in the year 2008. It has two floors with a total area of approximately 377 m^2. The area of the ground and first floors is around 210 m^2 and 167 m^2 respectively. The house is rectangular in shape, having an aspect ratio of approximately 1:1.5 with its length at an angle of approximately 25^o from the east-west axis. The orientation indication represents north. Both the floors of the house are divided into various zones depending on the functionality and the needs of the occupants. The ground floor is the living area comprising of reception, dining room, study room, kitchen and laundry, whereas the first floor is the sleeping area comprising of the bedrooms only. The first floors occupy less area in comparison to the ground floor and the remaining area is open to outdoors, thereby allowing the possibility to accommodate the direct expansion packaged air-conditioning units Figure 4.2.

4.8 Building Envelope Characteristics and Specifications

The building envelope comprises of walls, roof, floor, doors and windows working in tandem to deliver design performance. It has a great potential for heat exchange between indoor and outdoor environment, Table 4.3 explains the details of the case study.

Table 4.3: Building Features (KFUPM project Department)

Characteristics / Specification	Description of the Housing
Location	Dhahran (26.27 N latitude, 50.15 E longitude, and 17m above sea level)
Orientation	Front Elevation facing East
Shape	Rectangular
Floor to Floor Height	3.5m
Occupancy Density	8
Floor Area	377.3 m_2 (Gross); 210.0 m_2 (Ground Floor); 167.3 m_2 (First Floor)
WWR	10%
Weather File and RH	Dhahran:2012and 55%
Infiltration	0.5 ACH
Exterior Walls	16 mm Plaster (Dense) + 100 mm Concrete Block (Medium) + 50 mm Extruded Polystyrene + 100 mm Concrete Block (Medium) + 13 mm Plaster (Lightweight)
Roof	40 mm Concrete Tiles (Roofing) + 0.2 mm Polyethylene (High Density) + 50 mm Extruded Polystyrene + 4 mm Bitumen Felt + 59mm Cement Screed + 300 mm Reinforced Concrete (Cast, Dense)
Infiltration	1.25 ACH (Ground Floor), 0.75 ACH (First Floor)
Occupancy	7 People
Lighting Power Density	21 W/m_2 (Ground Floor); 13 W/m_2 (First Floor)
HVAC System Type	Residential System (Constant-Volume DX AC)

Figure 4.2: Building Floor Plans (KFUPM Project Department

4.9 Base Model Development and Formulation

4.9.1 Model Development

The desired objectives in this research are primarily achieved through a set of modeling exercises. A base case roof model will be developed for a residential building in KFUPM with the help of DesignBuilder. It provides a graphic user interface GUI in today's widely used energy simulation engine EnergyPlus and is popularly known to have varied graphical output features (Maile et al., 2007). This is based on four grounds, namely tool architecture & functionality, life-cycle usage, data exchange & interoperability and limitations. The workflow starts with selecting a location for carrying out the analysis. Then the tool allows the creation of building geometry and other defined parameters such as internal loads, construction types, windows, doors, lighting, material selection, HVAC systems. Thus, based on the specifications mentioned in the previous section, the construction of building envelope systems in DesignBuilder is described and discussed here. This includes the details of each surface composition, i.e. wall, roof, window and floor. Table 4.5 shows the summary of construction features of each thermo-physical system. In addition to these, emphasis is also given to infiltration in terms of airtightness depending on the number of openings, and organization and usage of the house. The airtightness in DesignBuilder is expressed in terms of a constant rate ac/h schedule. Each floor has been assumed to have different levels of airtightness. Though the standard value these days for airtightness has been adopted as 0.5 ACH, the same could not be observed in case of the base model development. As the lower level has many openings in comparison to the upper one, the airtightness is assumed to be 1 ACH and 0.5 ACH respectively.

4.9.2 Validation of the Model

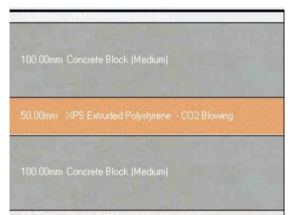
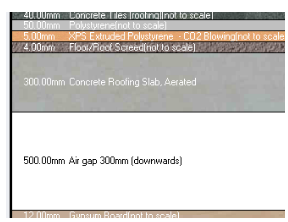
The model was validated by using data derived from an earlier field test. Energy monitors and data loggers where installed to measure the energy consumption of the reference KFUPM faculty housing during the peak summer period for approximately three months. The data collected from the field is use to validate the base model, this gives the opportunity to validate the base model with the summer season energy consumption data.

Table 4.4: Measured data collected from an earlier field test

Month	**Measured Data KWh/m^2**
July	25.8
August	28.1
September	23.8
Total	**77.7**

The data was used performed review of simulation model, simulation runs for verification of the base case model, customization of the green roof according to the local weather conditions, performing design optimization with the required and necessary data using a wide range of green roof options to investigate the potentials of green roof in reducing energy consumption in the climate under study. Finally, results derived from the modelled and experimental work in conjunction with cost data gathered from local and international manufacturers and contractors/product distributors is use to perform a cost benefit analysis of the green roof models.

Table 4.5: detailed component of the envelop system

Envelop System	System Description	System sections	U value (W/m2-K)	R Value (m2-K/W)
Roof	15mm roof Tiles +50mm Polystyrene+ 5mm Extruded Polystyrene+ 4mm roof Screed+300mm Concrete Roof slab+500mm Services duct(airgap) + 12mm gypsum board		0.360	2.78
Wall	16mm plaster layer+100mm Conc. block+ 50mm Extruded Polystyrene + 100mm Conc. Block + 13mm Plaster		0.46	2.15
Floor	15mm roof Tiles +50mm Polystyrene+ 5mm Extruded Polystyrene+ 4mm roof Screed+300mm Concrete Roof slab+500mm Services duct(airgap) + 12mm gypsum board		1.98	0.51
Window	4mm tinted glass +12mm air gap + 4mm tinted glass		2.7	0.51

4.10 Simulation Techniques for Energy Analysis

Residential energy model rely on input data from which it `s use to simulate energy consumption. The level of detail of the available input data can vary dramatically, resulting in the use of different modeling techniques, which seek to take advantage of the available information. These different modeling techniques have different strengths, weaknesses, capability and applicability. Though each technique had its impact on energy use individually, but a compendium strategy is look into for analysis, reference building has external structures of a typical of KFUPM building trends.

To evaluate the most energy and cost benefit savings potentials, three (3) different strategies were used.

1. Vegetative roof strategy
2. Flying roof strategy
3. Combined roof strategy

However, to simplify the analysis because of numerous repetition of configuration, the analysis is represented with following denotations Table 4.6:

Table 4.6: Roof type Strategy

Description		Denotation
Vegetative Roof		**Represented**
1	Green roof fully Covered	Type A
2	Green roof half Covered from East	Type B
3	Green roof half Covered from West	Type C
4	Green roof Long covered from North	Type D
5	Green roof Long covered from South	Type E
Flying Roof		
1	Fully covered with flying roof	Type F
2	Covered from the north	Type G
3	Covered from the South	Type H
Combined Roof		
1	Covered from the South with vegetation & flying roof from the north	Type I
2	Covered from the North with vegetation & flying roof from the South	Type J
	Reference Roof	Ref. Roof

4.10.1 Vegetative roof strategy

The first strategy considered for analysis was installing vegetation on the rooftop to cover the entire roof area approximately 175m^2square meters, as shown on Figure 4.3**.** The second strategy considered for analysis in this research was installing vegetation on the roof top halfway that is, dividing the roof top into two equal parts with one half having the vegetation from the north and the other half south with no vegetation as shown on Figure 4.4. The third strategy was having the vegetation on the south west rooftop and the other north east with no vegetation as shown on Figure 4.5**.** The fourth strategy was having the vegetation on the East north the fifth strategy is

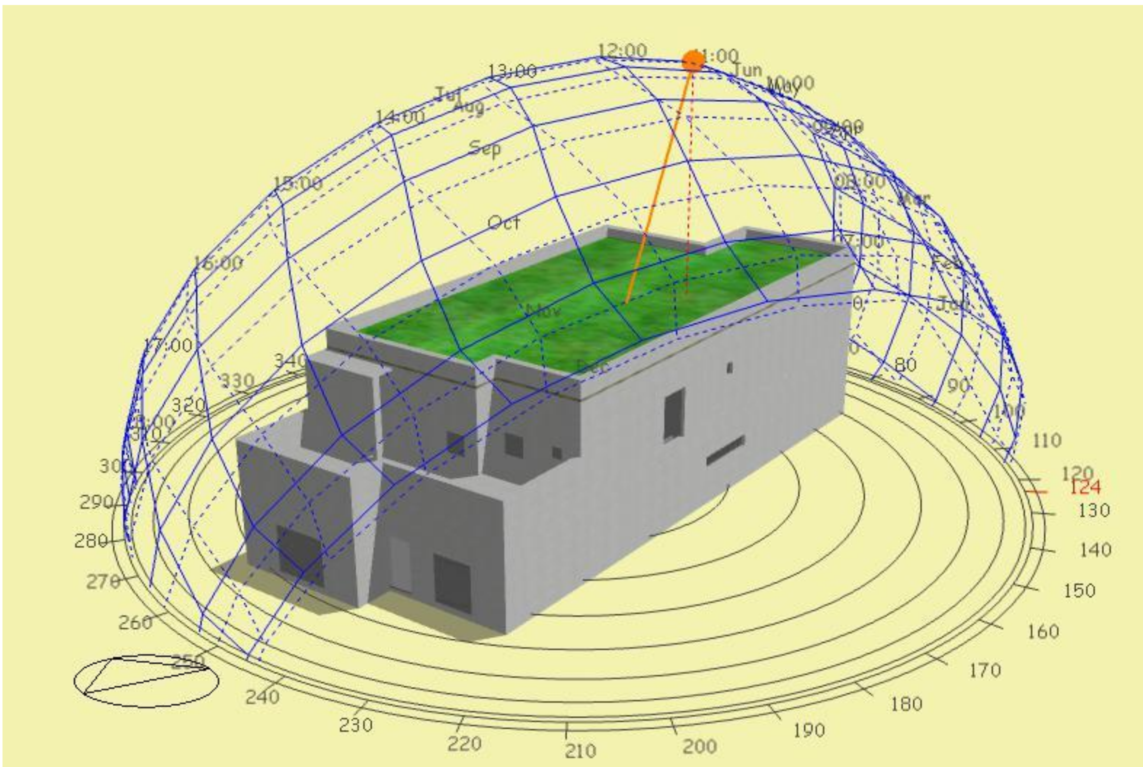


Figure 4.3: Type A green roof Strategy

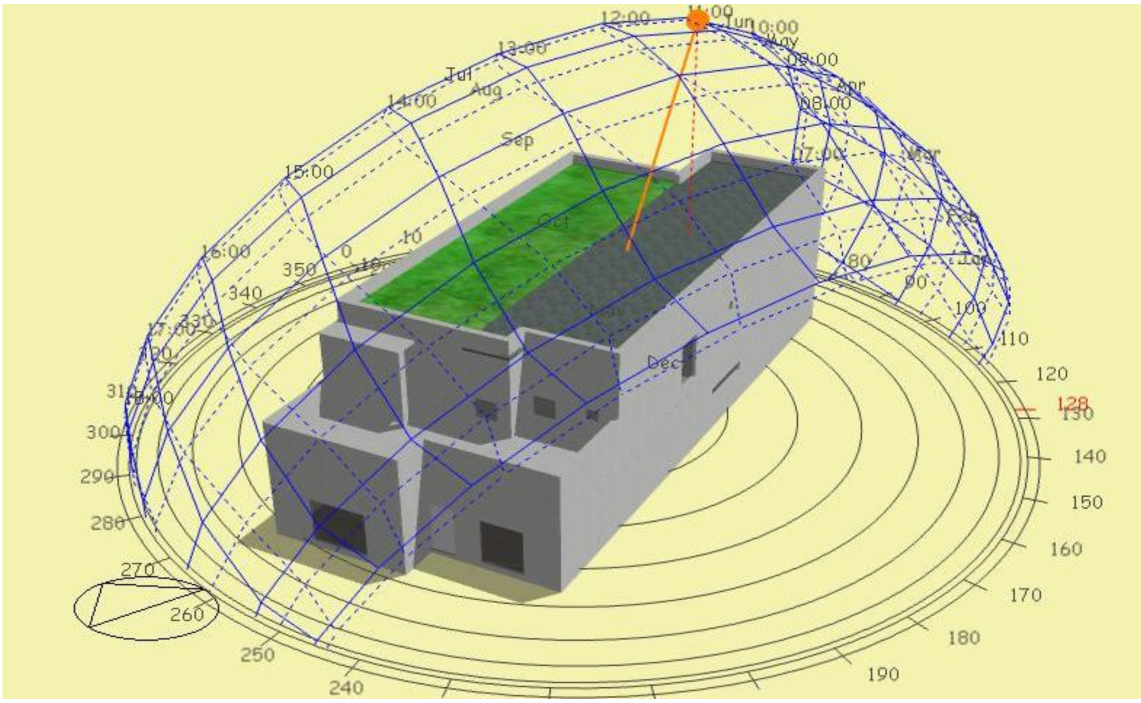


Figure 4.4: Green roof Type D

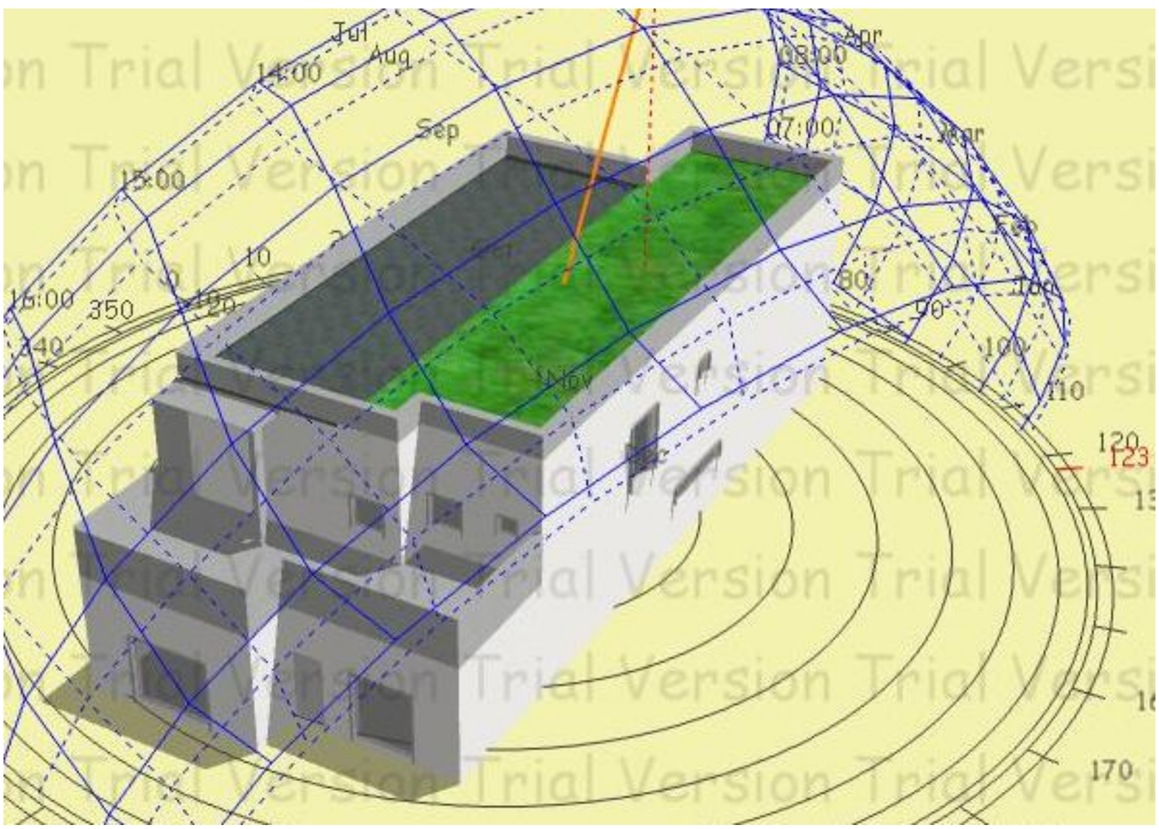


Figure 4.5: Green roof Type E

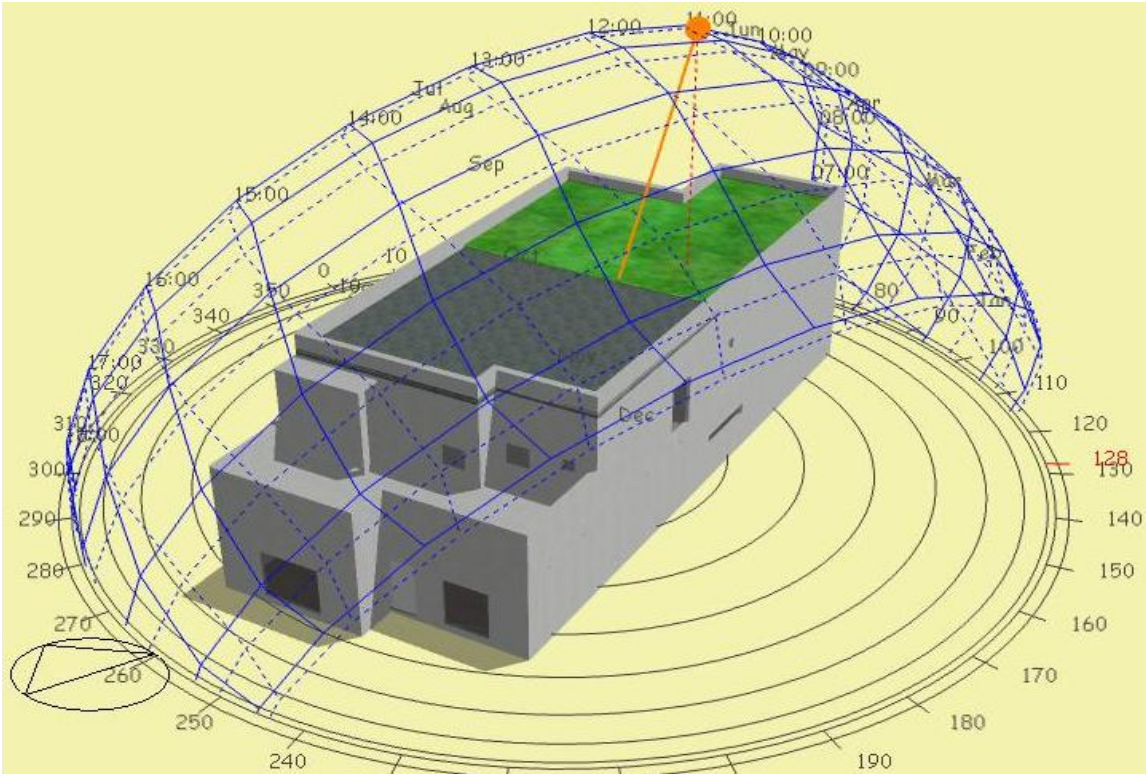


Figure 4.6: Green Roof Type B

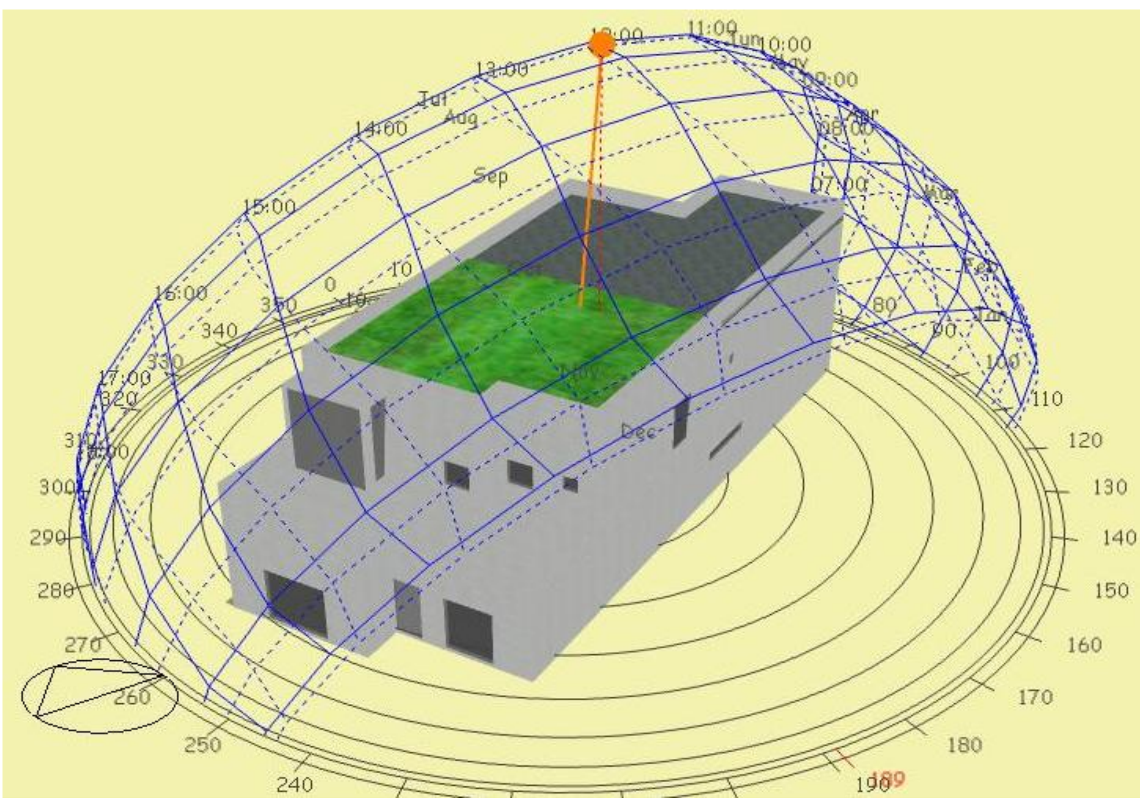


Figure 4.7: Green Roof Type C

4.10.2 Flying Roof Strategy

A fly roof (or flying roof) functions as a sunshade by blocking sun or other weather without trapping heated air in or against the main structure. The fly roof can use heat convection, stack effects and evaporative cooling as part of an air-conditioning system.

A double roof essentially uses a fly roof sometimes to create ducting between parallel roofs. A Fly roof can be permanent or temporary (seasonal), rigid or flexible, parallel to an underlying roof or not parallel, suspended over the main structure or a retractable window shade. Thus, in this research two options were evaluated to determine its performance with respect to energy consumption of the building. The first option was covering the entire roof with the thin layer of concrete (40mm thick) Figure 4.8, suspended at 1800mm above the normal structure, supported on six columns. Another strategy use or the second option adopted for the analysis is to have a flying roof in the south as shown on the Figure 4.9**,** the fly roof is inclined at 15 degree to the normal.

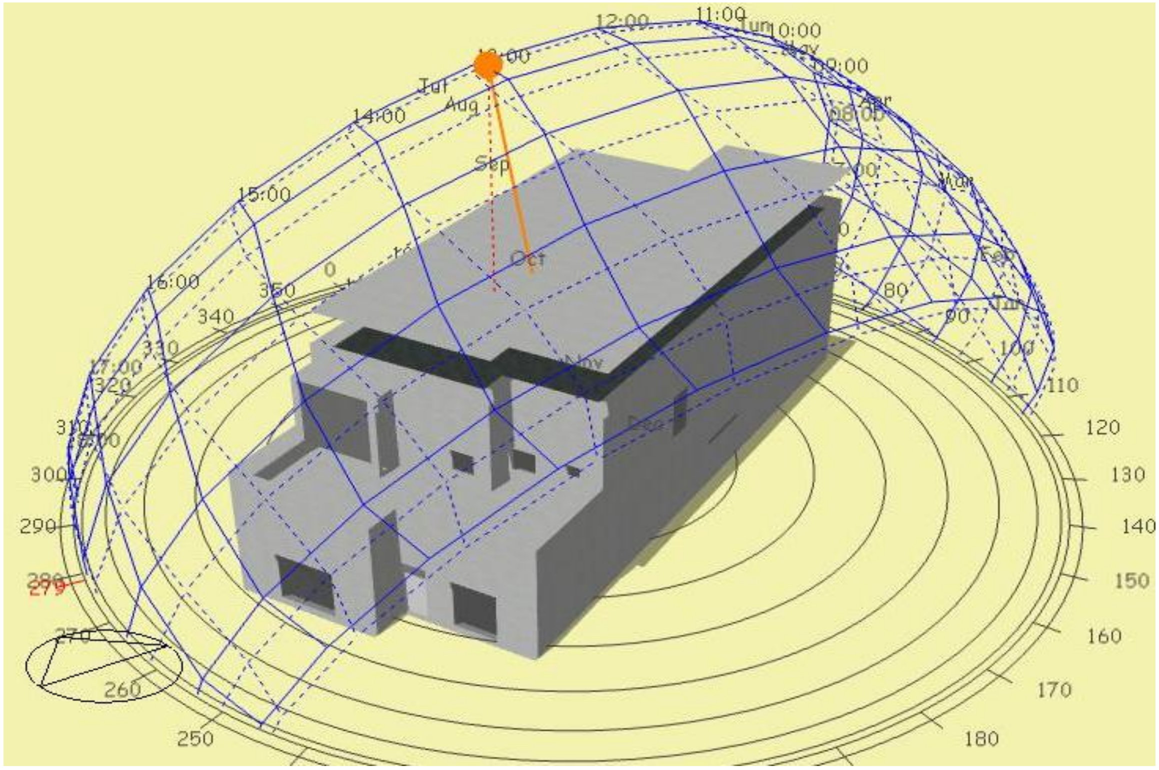


Figure 4.8: Fly Roof type F

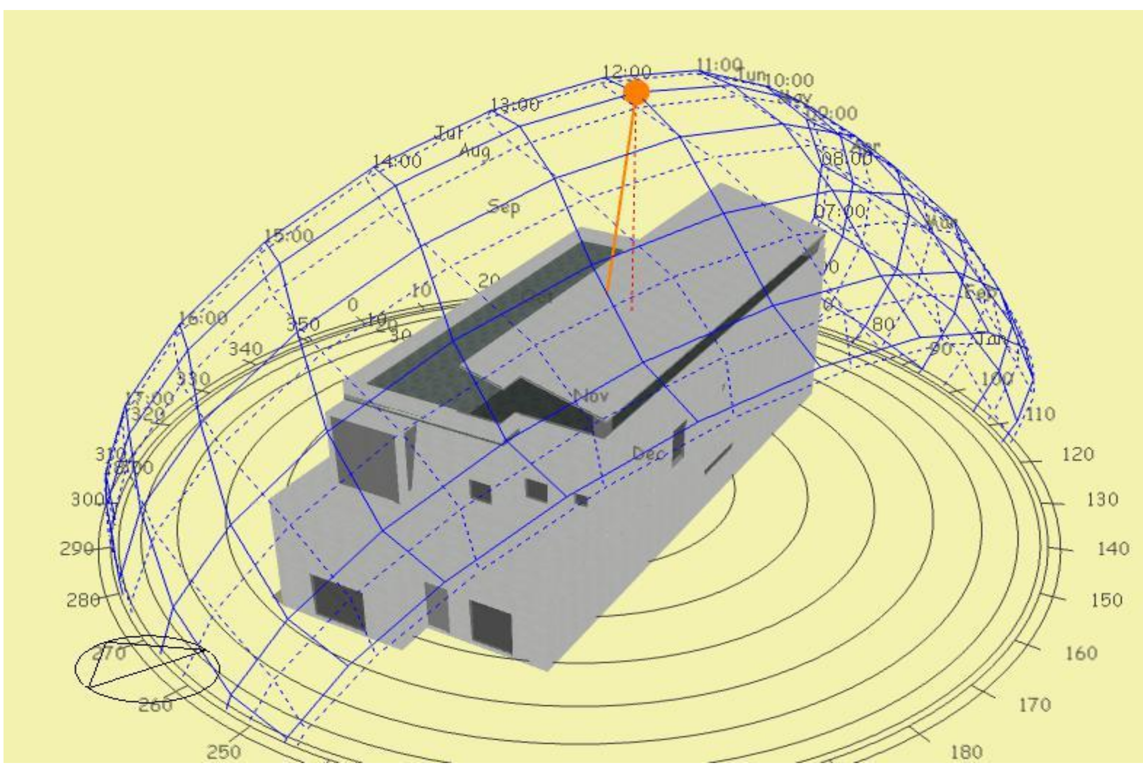


Figure 4.9: Fly Roof Type H

4.10.3 Combined Roof Strategy

The third technique used in this research was considering the combination of both strategies that is vegetative roof and flying roof to examine its effects on energy consumption. Two options were also evaluated the first technique or option is installing the vegetation from the south while having the fly roof from the north, inclined at 15 degree to the normal plane Figure 4.10, supported on three columns label as type I. The second option was installing the vegetation from the north while having the fly roof from the south, inclined at 15 degree to the normal plane Figure 4.11, supported on three columns.

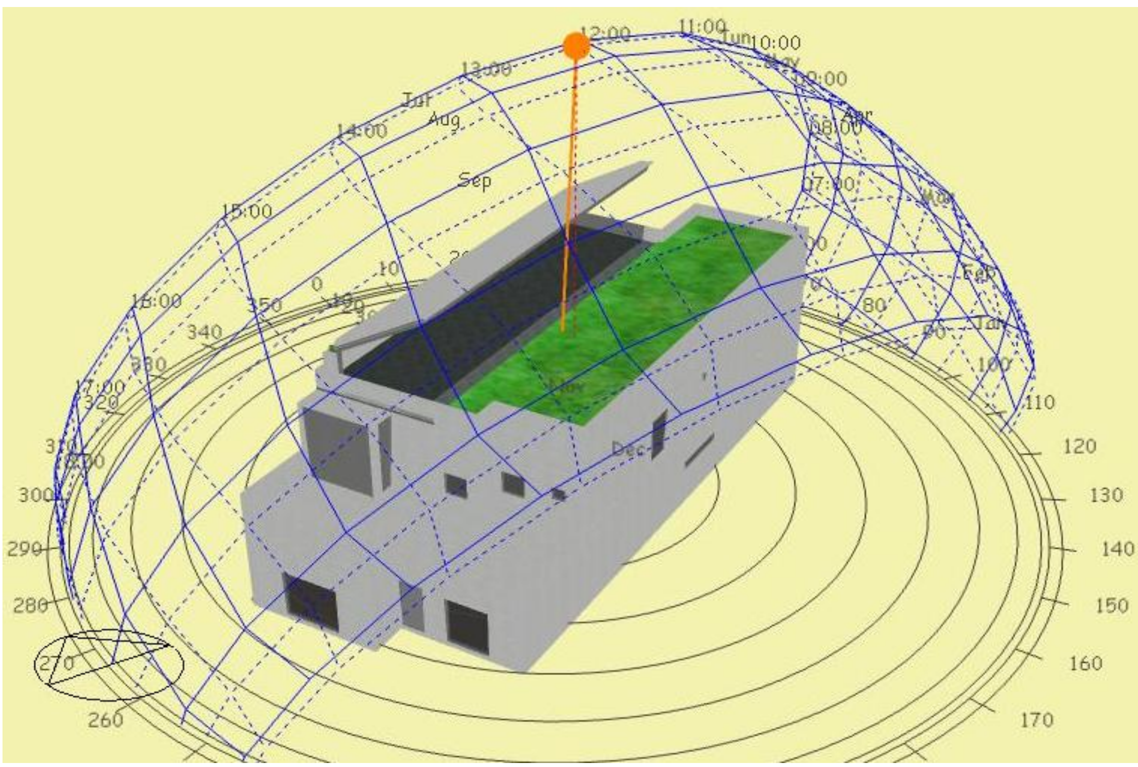


Figure 4.10: Combined Roof Type I

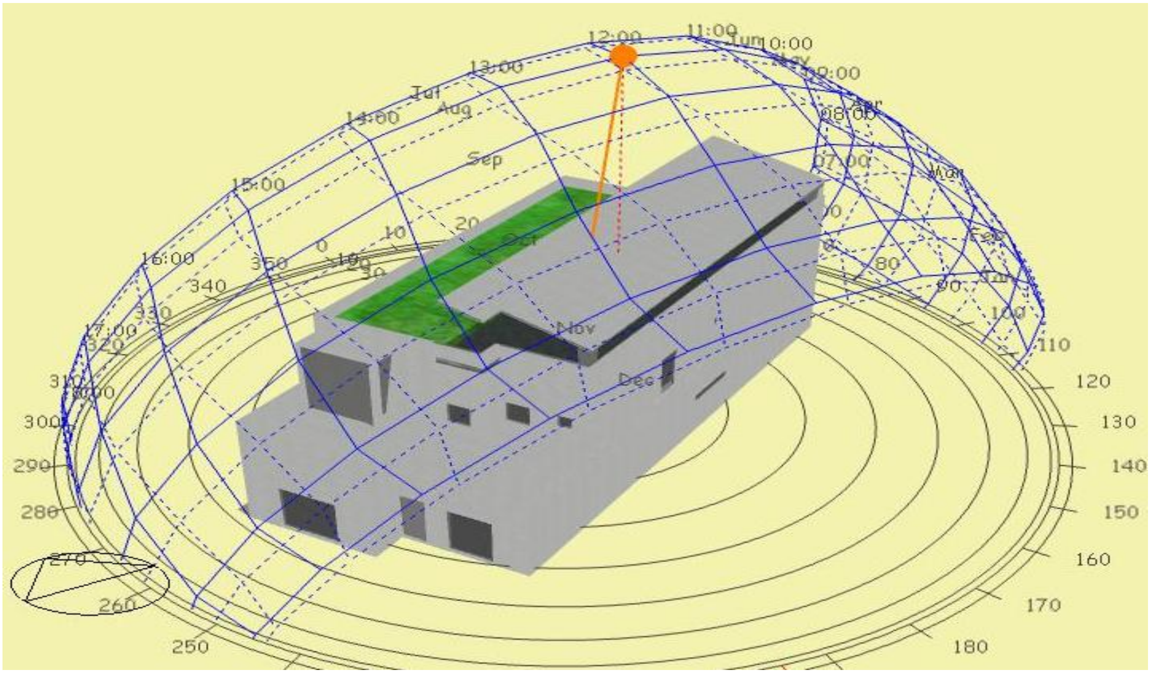


Figure 4.11: Combined Roof Type J

CHAPTER FIVE

RESULT AND DISCUSSION

In this chapter, the parameters of the green roof construction included (growing media depth, thermal bulk properties of soil, plant height, stomata conductance, and soil moisture conditions through irrigation). The program design builder solves the energy balance of a green roof from a process of radiative heat from the sun. This solar radiation is balanced by sensible (convection) and latent (evaporative) heat flux from soil and plant surfaces combined with conduction of heat into the soil substrate and long-wave (thermal) radiation to and from the soil and leaf surfaces, design builder simultaneously solves for soil surface and foliage temperature for each simulation runs (D.J. Sailor, 2008). The two heat flux equations shown below – one for the soil surface, the other for the vegetation canopy – are solved simultaneously for each simulations runs:

$F_f = \sigma_f$ [I_s(I- αf) +εf Iir↓ - εf Iir↓ - ε f σTf4 [+ σfεgεfσε1 (Tg4- Tf4) + Hf + Lf

F_g= (1- σf ( ] Is↓ (I- αg) +εg Iir↓ - εg Iir↓ - ε g σTg4 [- σfεgεfσε1 (Tg4- Tf4) + Hg+ Lg + K * ∂Tg∂Z

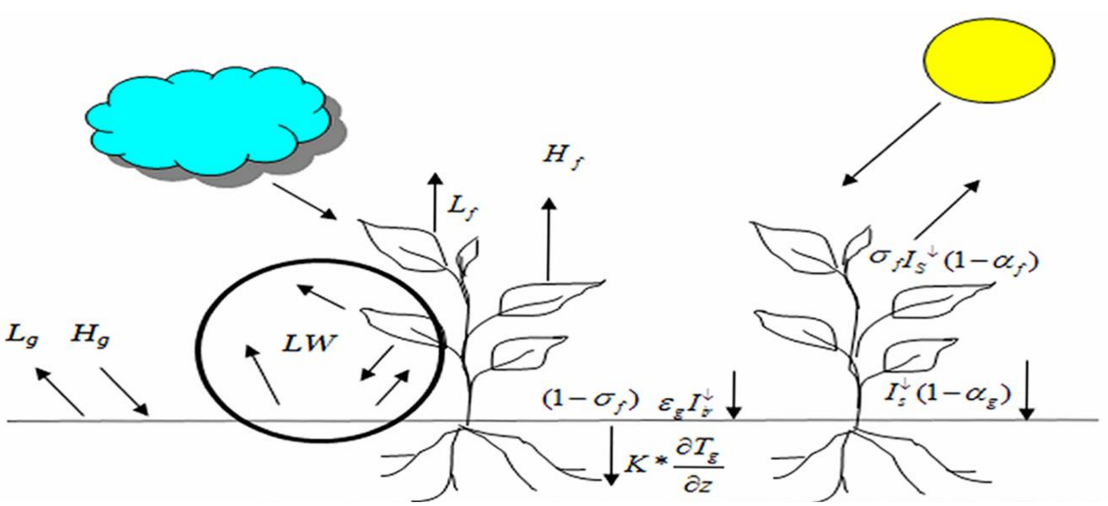


Figure 5.1: Sun effects on vegetation (D. J sailor 2011)

The developed and verified base case model of single family 4-bedroom university faculty housing was simulated in design builder program. Annual simulation was performed using the weather data file of Dhahran for the year 2012. Results of annual energy consumption for each month are shown in Figure 5.2. A total of 169.2 kWh/m^2 of energy is consumed by the base case model annually. It can be observed that August recorded a monthly high energy end use of 25.2 kWh/m^2 while February recorded the least with about 3.7 kWh/m^2. However, literature cites various techniques to evaluate the energy performance of a building with different indicators under development (Entrop et al., 2010).

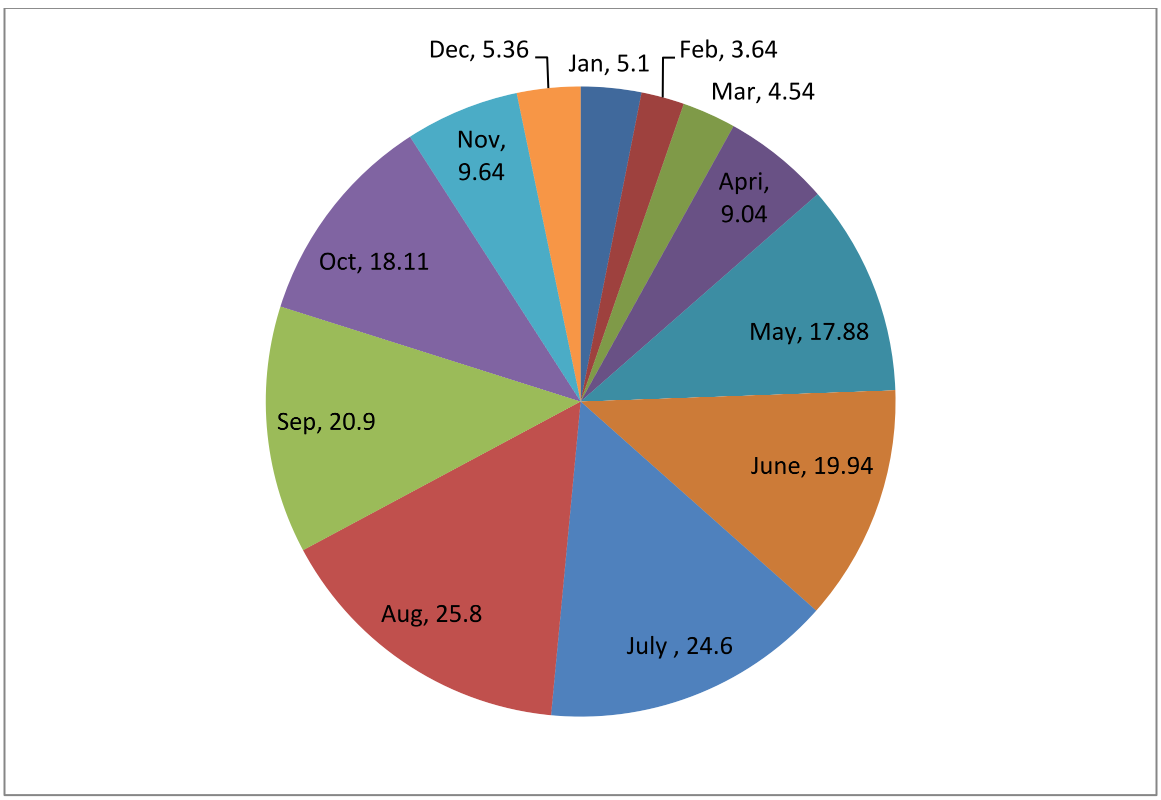


Figure 5.2 Monthly energy consumption of developed model

5.1 Energy Analysis

Further to the development of the base case, different roof systems as mentioned earlier were simulated, the simulation includes also roof insulation and the roof construction with the annual total energy evaluated. Different strategy that is vegetative roof, fly roof and combined roof with different placement either from (East, North, West, and South) and the criteria for selecting the best options in terms of energy reduction and cost are:

1. Percentage of Energy reduction
2. Feasibility
3. Maintainability
4. Cost
5. Return on Investment

Table 5.2 shows some information of basic design data about the components of the reference and Green roof systems, with the list of input parameters for green roofs. It is noteworthy that values for some of these parameters may have to be adopted from literature for validation of the based model Table 5.1 shows the values adopted.

Table 5.1: Green roof Model Parameters for DesignBuilder

S/No	Properties	Value
1	Thermal Conductivity (W/m-K)	0.295W/m^2-k
7	Height of Plants (m)	0.5m
8	Leaf Area Index (LAI)	5
9	Leaf Reflectivity	0.4
10	Leaf Emissivity	0.95
11	Minimum Stomata Resistance (s/m)	50
12	Max Volumetric moisture content at saturation	0.5
13	Minimum residual volumetric moisture content	0.2
14	Initial volumetric moisture content	0.5

Table 5.2: Green and Reference Component

Reference Roof	Green Roof
Sand Cement tiles	Vegetation
50mm Polystyrene Insulation	Growing Medium
Waterproofing Membrane	Filter membrane
60mm Sand/Cement Screed	Drainage layer
300mm Rib Slab	Sand Cement tiles
500mm Thermal Insulation(air gap)	50mm Polystyrene Insulation
12mm Thick Gypsum board Suspended	Waterproofing Membrane
	60mm Sand/Cement Screed
	300mm Rib Slab
	500mm Thermal Insulation(air gap)
	12mm Thick Gypsum board Suspended
	

To illustrate the range of simulation output results that might be expected, a matrix of simulations is presented below for three different strategies (i.e. Vegetative roof, Flying roof and combined due to the large possible number of combination, a summary of model output would include at least 2 combinations for each strategy. The green roof simulation described here has been successfully implemented in the EnergyPlus building energy simulation program. It has further been validated by applying it to data gathered from a detailed field study. In the validation, the model consistently produced the monthly energy consumption per square meter (KWh/m^2)

5.1.1 Vegetative Roof strategy

The implementation of this strategies have resulted to four different analysis, and simulating the effect of each type of strategy, it is obvious from Figure 5.2 green roof type A, with a least energy end use which consumes a total energy end used of $114kWh/m^2$ with a peak energy load around the months of July, August and September is consider the best option in the category, followed by type D having an energy end used of $128kwh/m^2$ as shown on Figure 5.5, with the monthly analysis when compared to the other options, which is type C, B and E. Figure 5.8 illustrates the results of the compendium strategies under the vegetative roof options. Thus, reference to the criteria for selection based on earlier mentioned, options, type A then type D and so on, see Figure 5.7

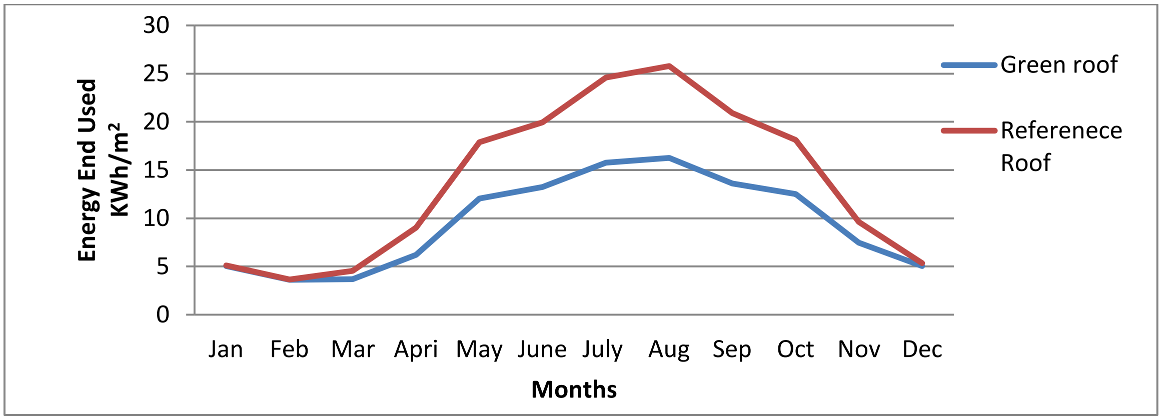


Figure 5.2: Green roof Type A: the energy end used in kWh/m^2

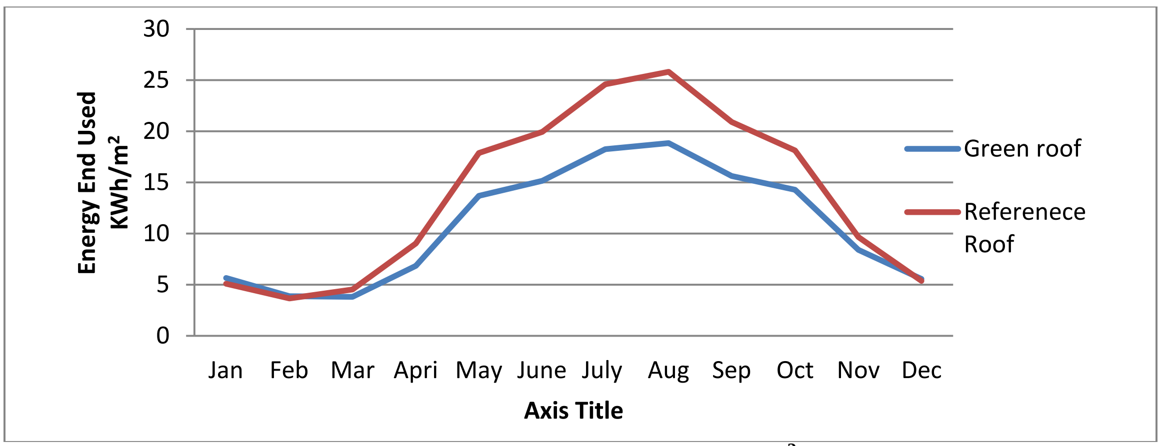


Figure 5.3: Green roof type B: Green roof type energy end used in kWh/m^2, referenced to the existing energy used

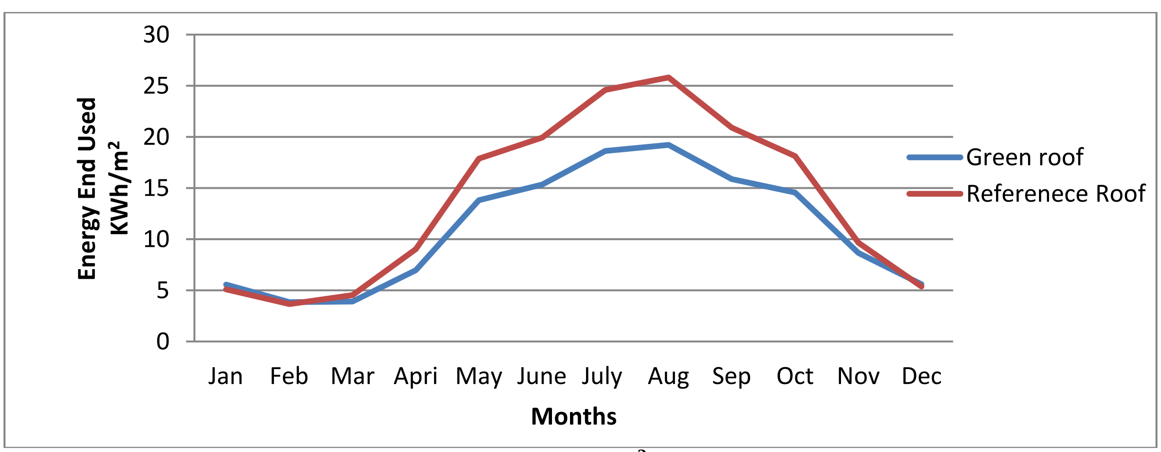


Figure 5.4: Green Roof type C: the energy end used in kWh/m^2, referenced to the existing energy used

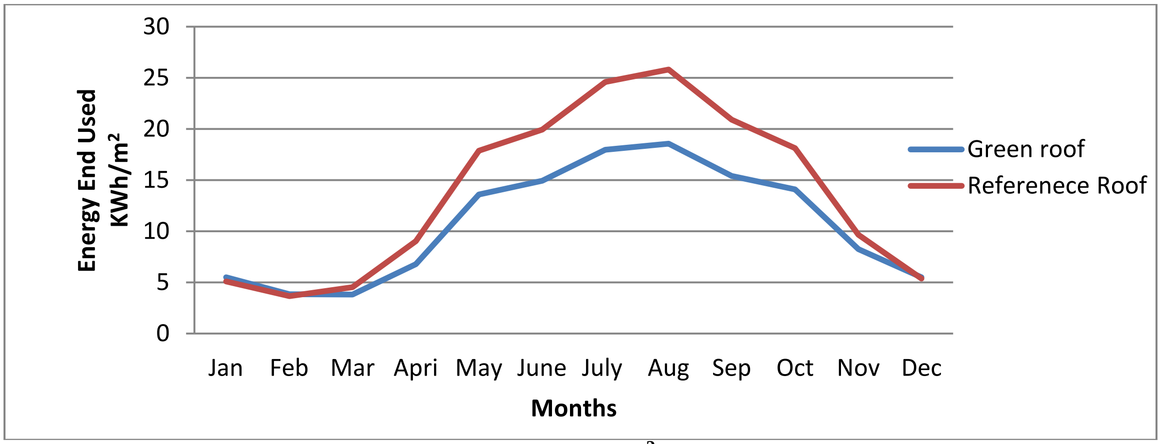


Figure 5.5: Green Roof Type D: the energy end used in kWh/m^2, referenced to the existing energy used

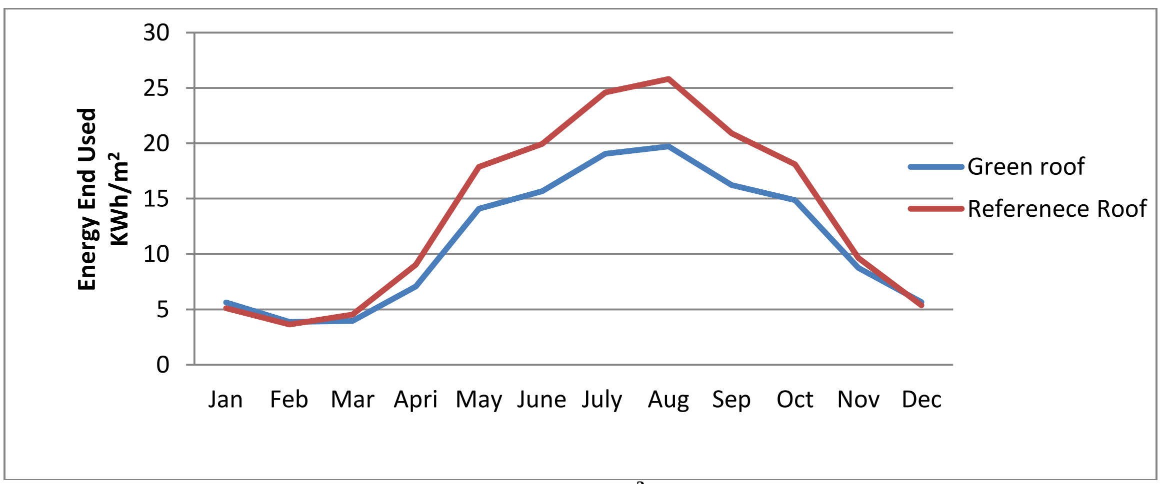


Figure 5.6: Green Roof type E: the energy end used in kWh/m^2, referenced to the existing energy used

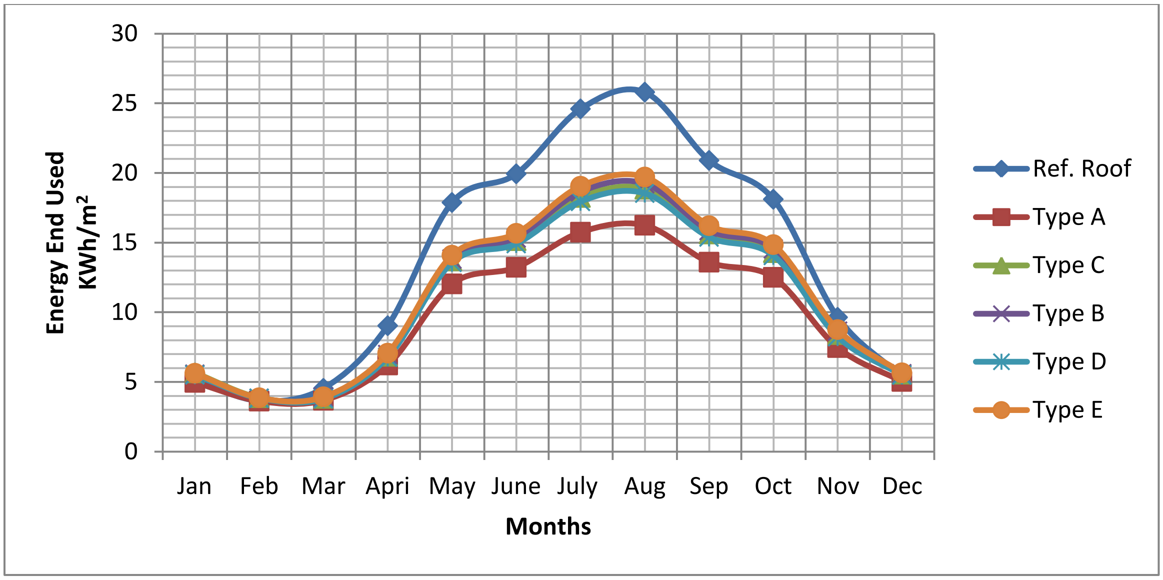


Figure 5.7: Vegetative Roof Strategies the energy end used in kWh/m^2, referenced to the existing energy used

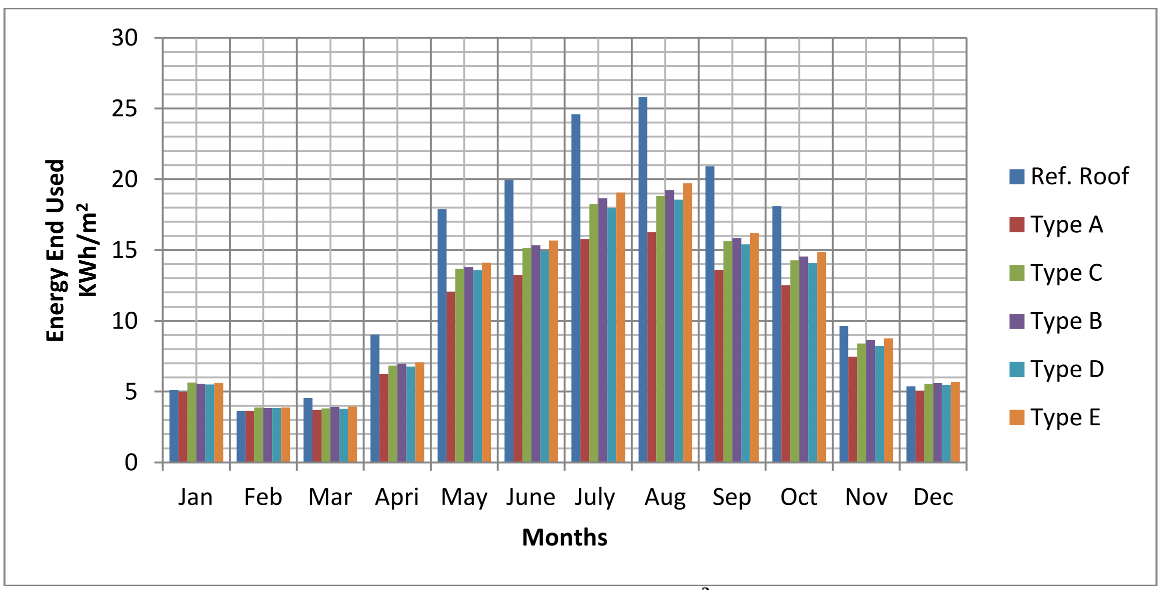


Figure 13: Vegetative Roof Strategies the energy end used in kWh/m^2, referenced to the existing energy used

5.1.2 Flying Roof Strategy

This option was considered as the second strategy for conducting the energy analysis for Dhahran weather climate 2012, two series of options were used, that is completely covered with thin concrete cover of 40mm thick, and the roof was suspended at a height of 1800mm above the conventional roof slab. The second series of options was to have the fly roof at an inclined angle of 15 degrees facing north, covering only half of the conventional roof, i.e. 88m2. After simulating the effect of each type of strategy, it was discovered that that fly roof cover inclined at 15 degree reduces the energy index by 23% Figure 5.10. While covering the entire conventional roof with the thin layer of fly roof reduce the energy by 15%. However, during the months of January, February and December, the total energy load required for heating exceed that of the reference roof, this is due to the additional shade provided making the roof cooler than ordinary, the effect of thermal mass is so significant with a conductivity 0.9 W/ m-K better. Figure 5.9 illustrates the results of the analysis.

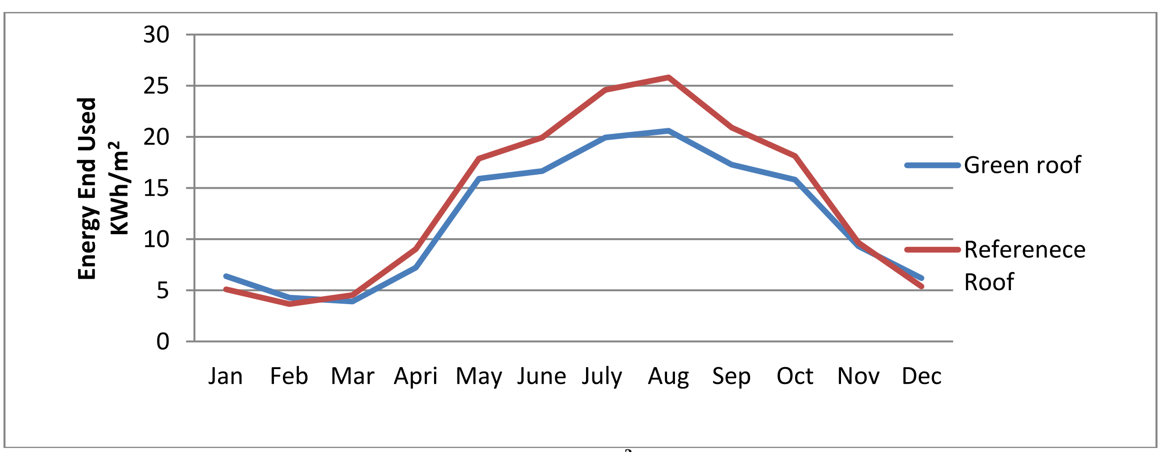


Figure 14.9: Fly Roof Type F: the energy end used in kWh/m², referenced to the existing energy used

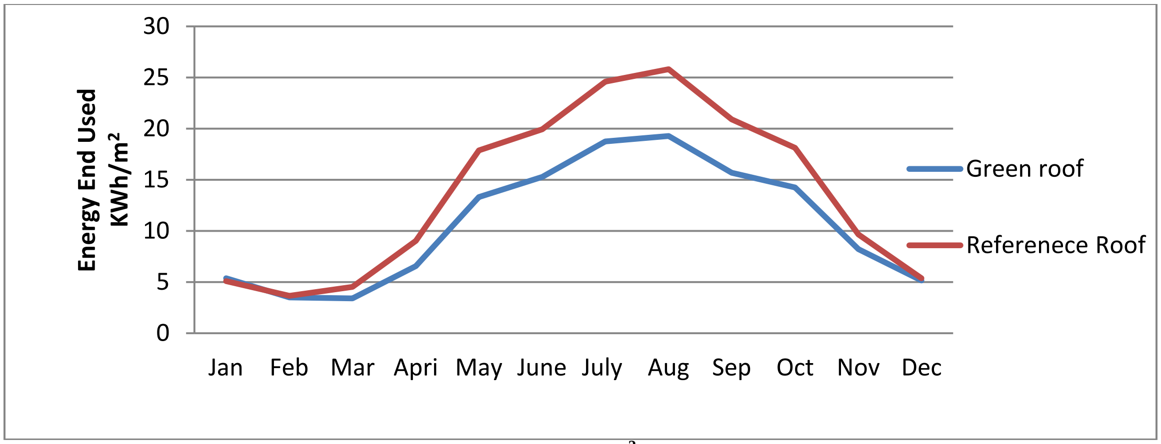


Figure 5.10: Fly Roof Type H: the energy end used in kWh/m^2, referenced to the existing energy used

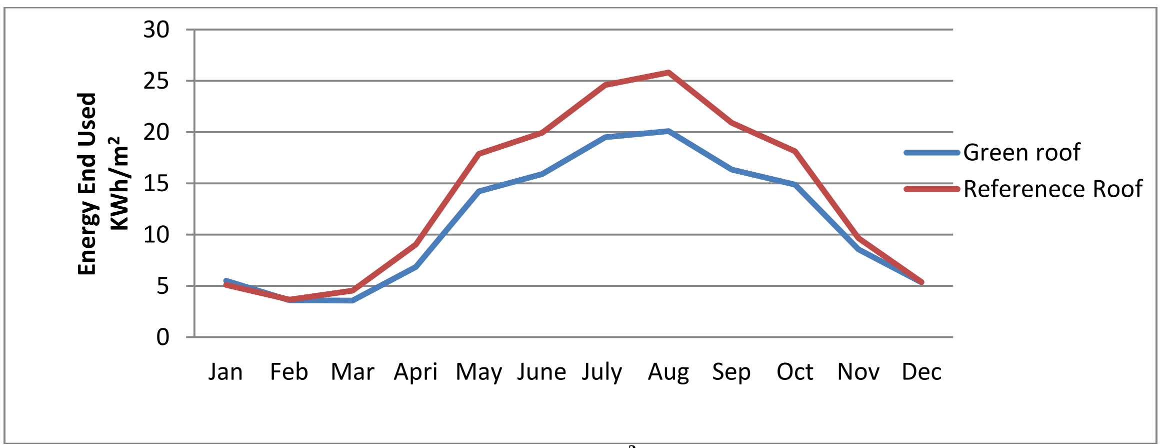


Figure 5.11: Fly Roof Type G: the energy end used in kWh/m^2, referenced to the existing energy used

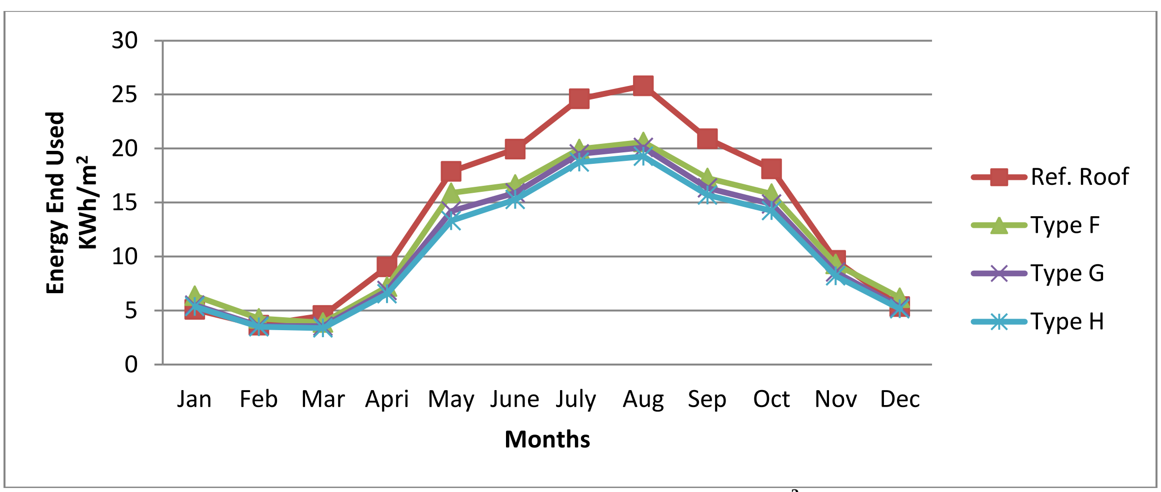


Figure 5.12: Summary of Fly Roof Strategy: the energy end used in kWh/m^2, referenced to the existing energy used

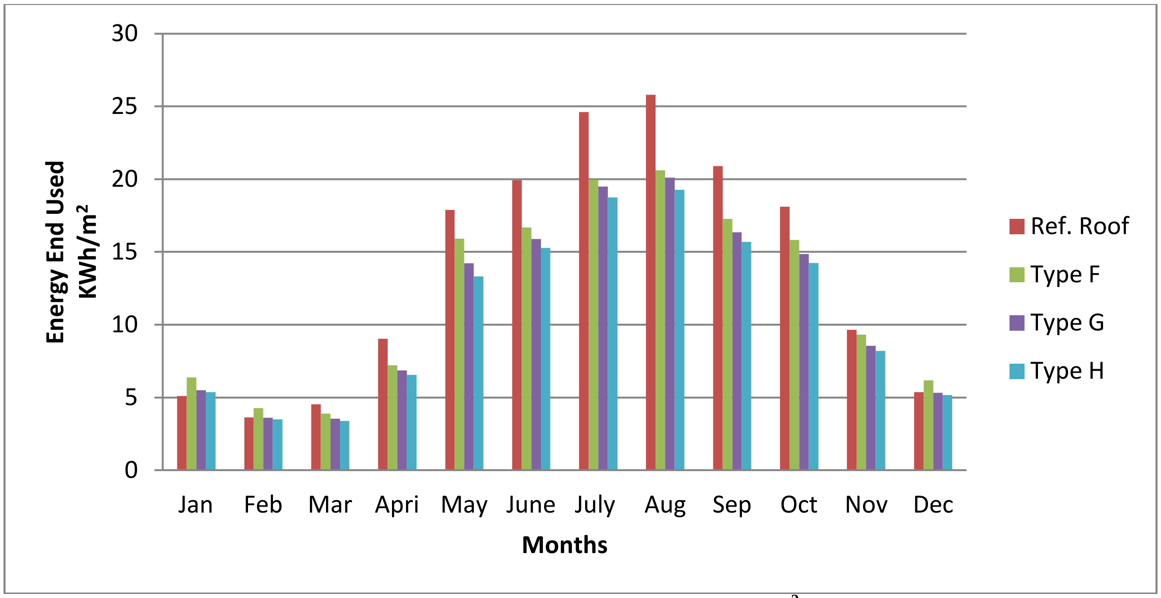


Figure 5.13: Summary of Fly Roof Strategy: the energy end used in kWh/m^2, referenced to the existing energy used

5.1.3 Combined Roof Strategy

A compendium strategy was considered as the final option to compare both initial strategies i.e. fly and vegetative roof. As shown from figure 2.14 types I represent energy end used with 109kWh/m^2, for all the months simulated August has the highest as compared to type J, with 117kwh/m^2, Figure 5.15 Thus, under this roof strategy type I present the best option based on the previously mentioned criteria.

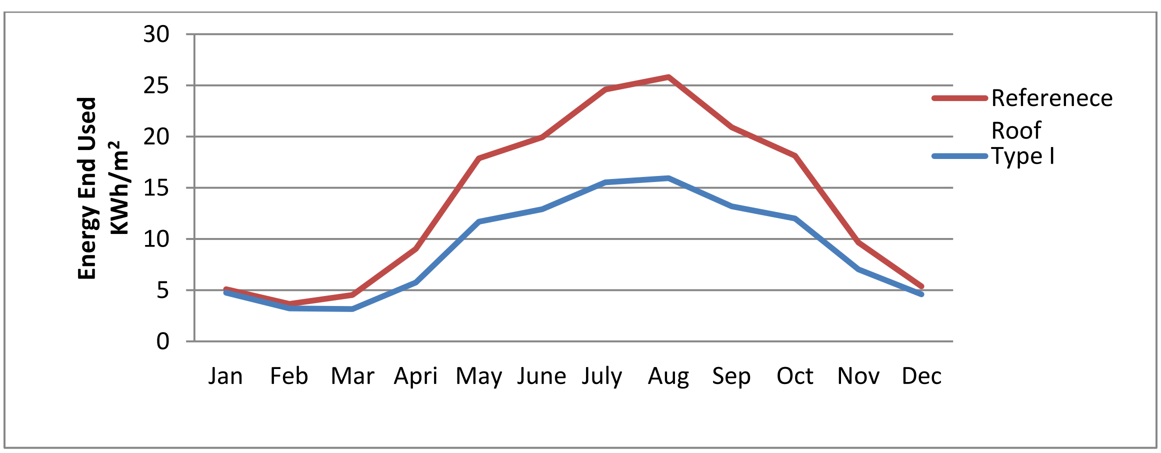


Figure 15: Combined Roof Type I: the energy end used in kWh/m^2, referenced to the existing energy used

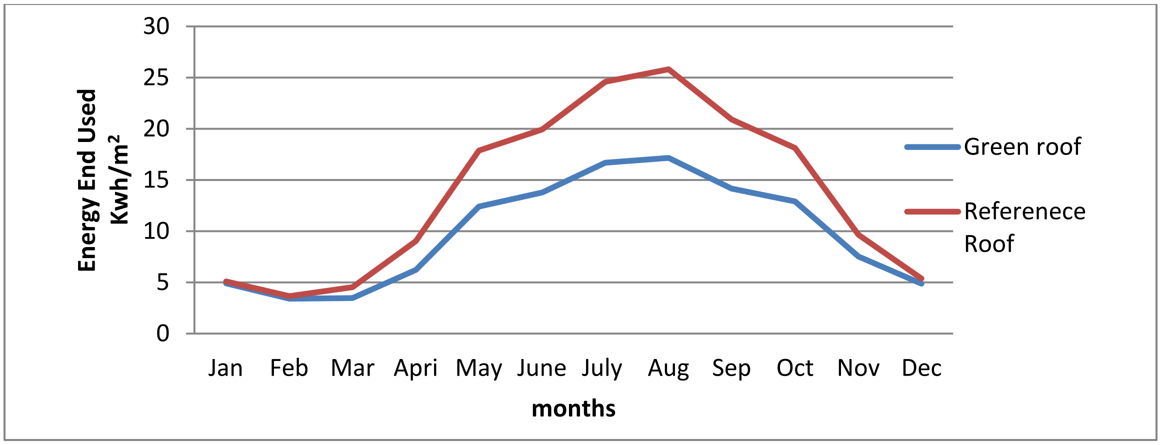


Figure 5.15: Combined Roof Type J: the energy end used in kWh/m^2, referenced to the existing energy used

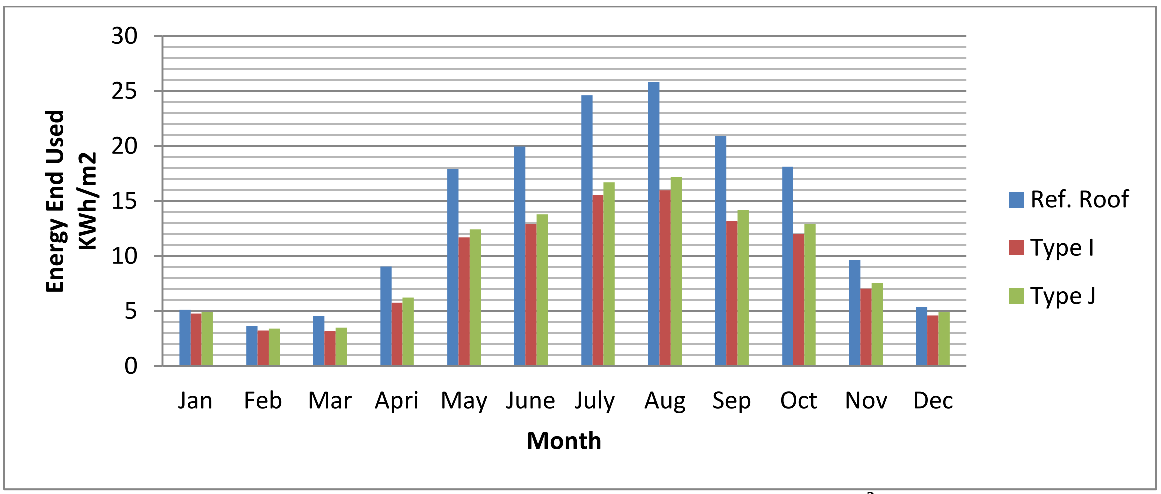


Figure 5.16: Summary of Combined Roof Strategy: the energy end used in kWh/m^2, referenced to the existing energy used

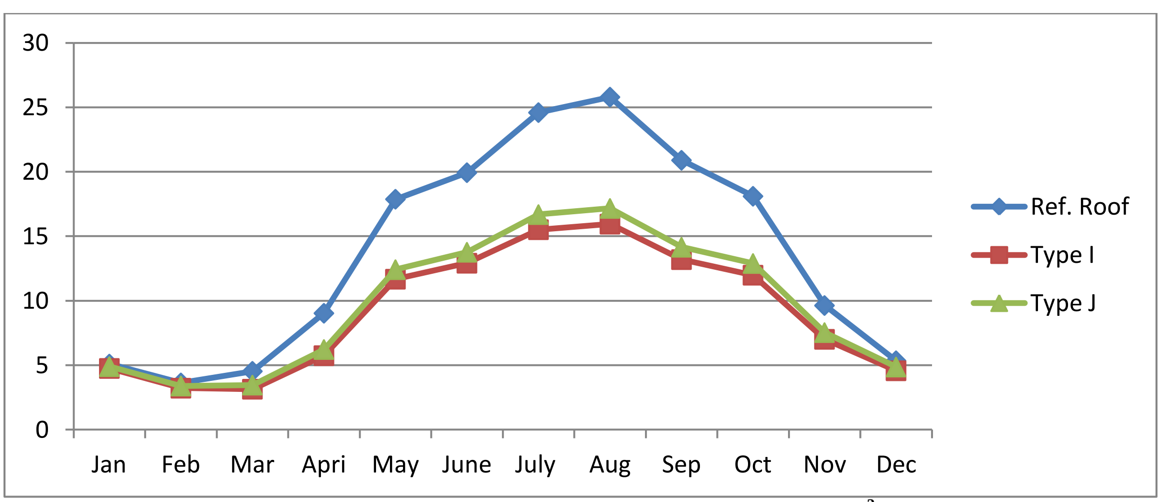


Figure 5.17: Summary of Combined Roof Strategy: the energy end used in kWh/m^2, referenced to the existing energy used

5.2 Summary of the strategies

Data analysis compared the performance of different green roof options, flies roof options and combined roof options, in terms of energy reduction potentials. Each one is unique in a way that it has been applied to the house in hot humid climate. Green roof is an entirely new approach accounting for better roof performance as a result of thermal mass and evapotranspiration. Fly roof is applied in the base case house model also and as an active dynamic air envelope system in a way to cut down heat gains, creating exterior shading to direct solar incidence on the roof top, thereby insulating the building envelope in the best possible way. Another method is by combining both fly roof and the vegetative roof which gives a potential energy savings. Building codes and standards help exploit valuable resources in a positive way thereby reducing adverse impact and enhancing environmental benefits. This section, therefore, presents the influence of all strategies on energy performance of the house. Figure 5.18 shows the energy consumption reduction. Table 5.2**,** shows that each strategy played it`s part in reducing the energy end use intensity to its greatest potential. Green roof type A reduce the energy index by 32%, fly roof type H and combined roof type I been new to Dhahran city in terms of analysis conserved 23% and 36% energy respectively.

Table 5.3: Annual Energy Consumption Reduction

	Annual Energy Consumption (kWh/m^2/)	**Energy Consumption Reduction (%)**
Base Case	169	-
Green Roof Type A	114	32%
Combined Roof Type I	109	36%
Fly Roof Type H	129	23%
ASHRAE Std. 90.1(2010)	118	31%
IECC 2013	127	20%

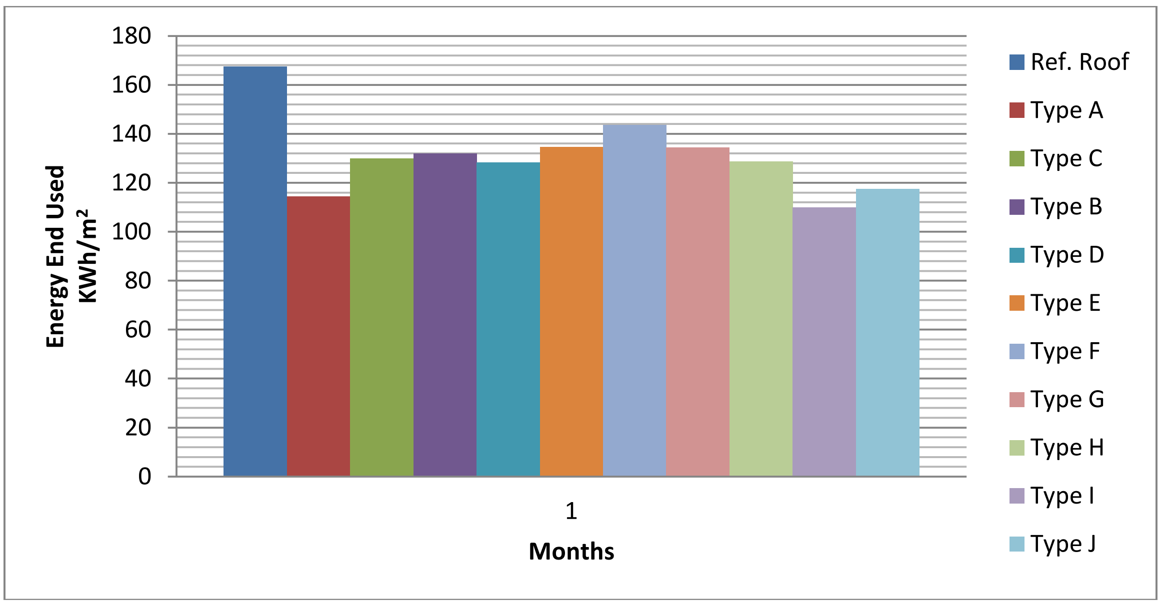


Figure 5.18: summary of energy end used in kWh/m^2, for all the strategies

5.3 Cost-Benefit Analysis of Green Roofs

5.3.1 Inflation and discount rate

Inflation and discount rate in this research were derived from the Saudi Central Bank as of February 2015 and are accounted for in the labor and materials and energy. The labor and materials cost growth rate was assumed to be 2% and was used in the costs, maintenance and replacement cash flows. The discount rate was carefully chosen to account for the cost of capital and was adopted as 2.1%.

The relative costs, cost-saving benefits and added value of a green roof versus a conventional roof over a 15- year timeframe was then accounted for and discounted back to present value. Four separate cash flows were created to allow data segregation and identification of the relative benefits:

- Installation, replacement and maintenance
- Energy
- Carbon reduction
- Real estate effects

5.3.2 Green roof installation costs

The analysis developed in this research was based on the reviewed cost of vegetation locally available and the material for the green roof construction. An extensive green roof is approximately assumed to cost SR 95 per square meter, including the soil and all equipment needed. The analysis found that the typical installation cost for a green roof depends on its size, with the price per square meter decreasing as the size increases.

5.3.3 Green roof maintenance

The first years of a green roof's existence are considered an establishment period, in which maintenance is critical to the roof's long-term success and maintenance requirements are the greatest. Maintenance of a green roof includes weeding, harvesting cuttings and distributing them in bare spots to improve coverage, checking for loss of growth medium, and inspecting for other potential watering problems. Maintenance costs will be higher any time a green roof includes a landscaped design, as workers will also need to spend time maintaining the design aesthetic. A typical maintenance crew includes two workers, though more may be needed for a larger roof. For this analysis, labor hours were rounded up to the next half-day for cost estimating purposes. A minimum of four maintenance visits per year is assumed for this study. The typical labor requirement is 2 person-hours per 175 square meters at SR 30. Maintenance requirements will decrease after the establishment period; this analysis assumes a reduction to two visits a year for this type of green roof. Thus, to estimate the value of green roof reference to the existing conventional roof in relation to energy and other associated benefits. The Principal cost (The original amount invested, separate from earnings) and the net present value NPV need to be determined, net present value (NPV) is a measure of the potential profitability of an investment. It takes the expected value of the future costs and benefits associated with this investment, and accounts for the effect of inflation. A positive net present value means an investment will produce greater returns over the time frame being considered than an alternate investment.

Therefore, to find the NPV using the interest table of 2% compound factor over 15 years, we used the following equation:

NPV = Initial cost + [annual maintenance cost](P/A, 2%, 15) + major maintenance cost [(P/A, 2%, 3) + (P/A, 2%, 6) + (P/A, 2%, 9) + (P/A, 2%, 12)]

To select the most beneficial green system roof assembly among different alternatives, we have to use the benefit to cost analysis. The equation to determine the benefit to cost ratio is as follows:

The benefits to cost ratio = $\frac{\boldsymbol{Annual\ benefit - Annual\ disbenefits}}{\boldsymbol{Annaul\ Cost}}$

- The annual benefits are advantages, express in terms of monetary value to the owner (SR, $ etc). In this case, the annual advantages are annual monetary value of the energy savings, after implementing the assembly of a particular green roof.
- Disbenefits are disadvantages, expressed in terms of a monetary value to the owner. i.e. riyals, dollars, etc.
- The Costs are anticipated expenditures for construction, operation and maintenance.

The benefits to cost ratio B/C = $\frac{\boldsymbol{Annual\ benefit - Annual\ disenefits}}{\boldsymbol{Annaul\ Cost}}$

- If the B/C ratio is 1.0, this means that the extra benefit(s) of the higher cost alternative justify the higher cost.
- If the B/C ratio is 1.0, this means that the extra cost is not justified and the lower cost alternative is selected.

$$= \frac{Annual\ Energy\ Savings}{Annual\ Cost}$$

Therefore, by substituting the calculated figures for all the strategies as shown in Table 5.3

Table 5.4: Economic Evaluation of Efficient Strategies

		Type A	Type B	Type E	Type F	Type I
S/No.	**Parameters**	**Amount (SR)**	**Amount (SR)**	**Amount (SR)**	**Amount (SR)**	**Amount (SR)**
1	Principal	15,429	7,715	7,715	4,500	7,715
2	Fly roof					1500
3	Water Consumption	890	445	445		445
4	Major maintenance after 3 yrs	1,800	900	900	300	900
5	Maintenance	3030	1515	1515	1500	2000
6	Major Energy Savings	2,000	1,461	1,279	915	2,462
	Total Cost	21,149	12,036	11,854	6,300	15,022
	Po	71,837.82	35,919.41	35,919.41	24,780.46	43,651.27
	NPV	5,590.42	2,795.25	2,795.25	1,928.42	3,396.94
	Benefit-Cost Ratio	0.36	0.52	0.46	0.47	0.72

The analysis initially revealed the performance of the simulated options appealing based on the effect on energy reduction, however, with the economic analysis, it suffers a setback in terms of justifying the cost to benefit ratio or its economic importance, when compared between the implemented options based on a range of benefits to the Cost. An economic scale indicator of ≥ 1 (Justified) or < 1 (not justified) was used to determine its cost to benefit ratio for a period of 15 years. Analysis result shows that all the analyzed strategies have their scale less than 1, this implies that that the extra cost is not justified and the lower cost alternative is to be selected (referenced Roof). See Figure 5.19

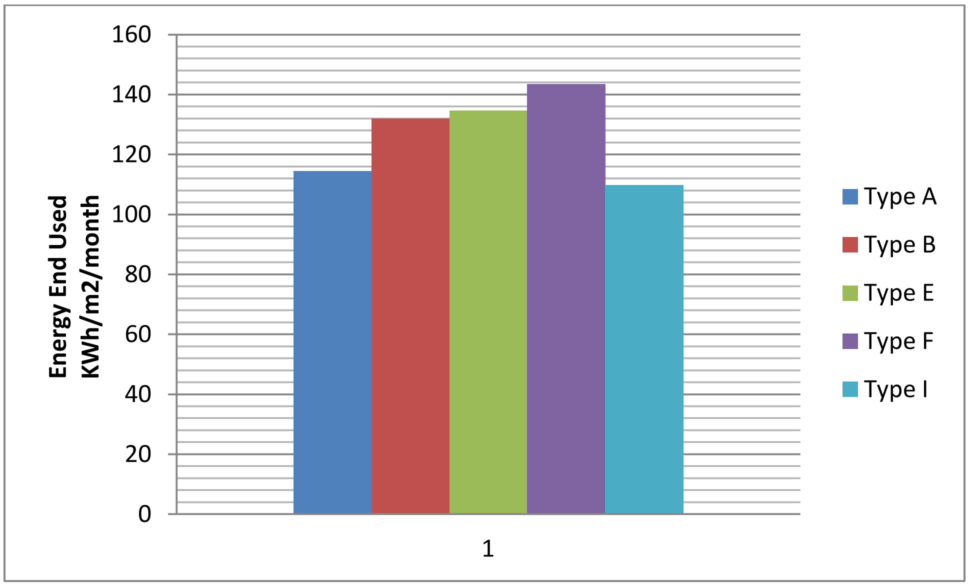


Figure 5.19: summary of energy end used in for kWh/m^2

5.4 Other Financial Impacts (less realizable)

Further to the initial cost, an analysis was also conducted to identify the more important variables based on their ability to impact the total NPV. The factors that significantly influence the value/costs of a green roof are:

- Mitigation of heat Island effect
- Habitat Creation
- Air quality improvement
- Carbon Reduction
- Longevity of Roof membrane
- Property Value

As discussed in section3.4, though the real value is not commonly found in literature, consequently effort is made to quantify the value for each of the environmental benefit associated with implementing the project, thus further benefit were realized and converted into monetary value, as shown in Table 5.4. Hence, analyses were reviewed and result shows a significant difference with type I with an economic indicator of 1.88 as the most cost effective while type B & E as the second most effective, with an economic indicator of 1.38 and 1.31 respectively. Whereas type A that had the most energy saving has the least cost effectiveness**.** See Table 5.5

Table 5.5: Monetary values for environmental benefits

S/No.	**Financial Impacts**	**Amount (SR)**
1	Mitigation of heat Island effect	525
2	Habitat Creation	350
3	Air quality improvement	17
4	Carbon Reduction	503
5	Longevity of Roof membrane	700
6	Property Value	3000
	Total	**4780**

Therefore, the equation was reviewed to consider the environmental benefits in to the analysis, thus, the below equation is used.

$$\mathbf{B/C} = \frac{\textit{Annual Energy Savings} + \textit{Annual Environmental benefits}}{\textit{Annual Cost}}$$

Hence, by substituting the calculated figures for all the environmental benefits accrued as a result of implementing the proposed energy efficient strategy, the benefit to cost ratio was evaluated and the most effective project to be implemented was determined as shown in Table 3, the most cost effective and return on investment is type I, though it has only

$88m^2$ covered with vegetation, but it also provide the most energy efficient option in term of reducing the annual energy consumption of the building.

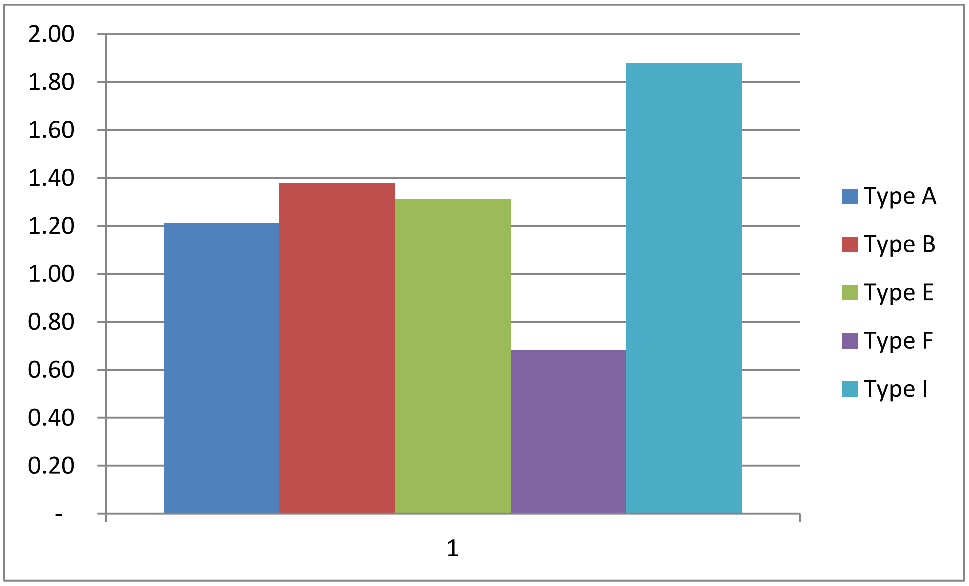


Figure 5.20: summary of benefit cost ratio

Table 5.6 Economic & Environmental Benefits Evaluation

		Type A	Type B	Type E	Type F	Type I
S/No.	Parameters	Amount (SR)	Amount (SR)	Amount (SR)	Amount (SR)	Amount (SR)
1	Principal	15,429	7,715	7,715	10,200	7,715
2	Fly roof					1500
3	Water Consumption	890	445	445		445
4	Major maintenance after 3 yrs	1,800	900	900	300	900
5	Maintenance	3030	1515	1515	1200	1500
	Environmental benefits	4780	2390	2390	500	2880
	Electricity Savings	2,000	1,461	1,279	915	2,462
6	Major Energy Savings	6,780	3,851	3,669	1,415	5,442
	Total Cost	21,149	10,575	10,575	11,700	12,060

Po	71,837.82	35,919.41	35,919.41	26,625.70	37,226.67
NPV	5,590.42	2,795.25	2,795.25	2,072.01	2,896.98
Benefit-Cost Ratio	1.21	1.38	1.31	0.68	1.88

CHAPTER SIX

CONCLUSION AND FUTURE WORK

6.1 Conclusions

This chapter summarizes the major contribution by this thesis. The main objective set to accomplish the task was to investigate the energy saving potentials of green roof and evaluate the savings or benefits against the cost to determine its economic effectiveness, for a hot-humid climate as characterized by the weather in Dhahran. A 4-bedroom single-family faculty residence at King Fahd University of Petroleum & Minerals (KFUPM), Saudi Arabia, depicting the modern regional building design trends is considered in the study. A base case simulation model of the house was developed using state of the art software tool (DesignBuilder), and the real time energy consumption data for three months during the summer season from July to September was obtained and used to validate the base case model. In this work, various strategies were investigated to determine their influence on energy performance of the studied house. The strategies investigated included vegetative green roof, fly roof and a set of green roof and fly roof combinations. The options were applied on the developed base case to obtain an optimized energy performance. Energy performance indicator kWh/m^2 was utilized to assess the impact of each option. The performance of the energy efficient enhanced roof was compared against that of the conventional roof through a detailed energy analysis. The result gives an annual energy consumption of $169.2 kWh/m^2$ per year for the base case. The work presents a compendium strategy that shows a combination of green roof and fly roof that reduces the annual energy consumption by 36%, thus, decreasing the energy index of the house from 169kWh/m^2 to 109kWh/m^2 per year, while vegetative roof reduces the energy index to 114kWh/m^2 per year.

Based on the first research objective, the most effective option in achieving the significant reduction is combined roof system type I, with an annual energy reduction of 36%. It conforms to the minimum requirement by ASHRAE Standard 62.2 and IECC 2013, which specify 30% and 10% in energy reduction for an existing building respectively. However, with the economic analysis, it suffers a setback in terms of justifying the benefit to cost ratio or its economic importance when compared with other options. An economic scale indicator of ≥ 1 (Justified) or < 1 (not justified) is use to determine its benefit to cost ratio for a period of 15 years. Result show that all the analyzed strategies have their scale less than 1, this implies that the extra cost is not justified and the lower cost alternative is to be selected (referenced roof). Consequently effort is made to quantify the value for each of the environmental benefit associated with implementing the project, thus further benefit were realized and converted into monetary value and added to analyzed result, a significant improvement on the benefit to cost is realized. The most cost effective has an economic indicator of 1.88, while other analyzed options have an economic indicator of 1.38 and 1.31 respectively.

Therefore, Green roof turnout to be available technology that can exploit our underutilized roof spaces. The use of green roof provides a potential solution to some of the setback associated with energy conservations in buildings. It is clear that green roof can be used judiciously in both new and old buildings. Building equipped with green roof will have greater chance of regulating its internal temperature due to evapotranspiration, thus, reducing the energy demand for cooling. Studies have suggested that hotter and drier climate will benefit more from the effect of green roof in cooling demand. Native species of plant with high succulence leaf and high water holding capacity will demonstrate greater survival for the weather climate of Dhahran. Finally green roof can help on the path toward achieving a more sustainable building and conserve our environment.

6.2 Future Work

This study has successfully carried out the desired research objectives on an existing single-family house. A set of green roof and fly roof combinations were applied on the developed base case and an optimized energy performance was achieved when compared against that of the conventional roof. However, further research is recommended on the following areas:

1. Research on design and material selection for green roof should continue, with more pilot studies. Green roof can also be used to mitigate environmental impacts associated with problems such as leaching, leakage, etc.

2. In this research, properties of vegetation such as Leaf Area Index (LAI), Thermal Conductivity (W/m-K), Thermal Absorptance (emissivity), Height of Plants (m), Solar Absorptance, were adopted from literature; further study should be conducted to determine the real properties based on native plants species.

3. Most of the heat gains are through wall system. However, in this research all walls simulated are considered south & north facing. Thus, the effect of different orientation of all wall needs to be investigated. Acceptable form and window area of the house also need to explore to determine acceptable daylight factor.

4. External and internal shading devices have significant effect on amount of heat gain and daylight. However, the building used in this study have no shading devices, Thus, the assessment of energy performance for a wall with different shading devices in residential building needs to be evaluated.

5. Different properties of wall insulation can affect the energy performance significantly. In this research, polystyrene insulation is considered, as well. The effect of different walls with different thermal insulation such as air gap is important to be investigated. In addition, in this research common type of 4 mm double tinted glass was use for all simulations, however properties of glass are important factors and they have a significant influence on the amount of heat gain and daylight. The effect of different glass materials on optimum WWR and SSP Ratio can be computed as further research.

6. Economic analysis should also be conducted on any sustainability related strategies of reducing energy consumption and environmental related issues, as can be seen from this research all the analysis on the energy consumption seems appealing but the cost to benefits ratio prove otherwise.

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